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Computational Tool for Estimating Pumped Hydropower Generation a MATLAB GUI

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Anahtar Kelimeler

Matlab
GUI
Pompajlı Hidroelektrik
Yenilenebilir Enerji

Graphical/Tabular Abstract (Grafik Özet)

This study aims to develop a user-friendly MATLAB GUI for designing Pumped Storage Hydroelectricity (PHS), emphasizing its eco-friendly and efficient nature crucial for sustainable development. / Bu çalışmanın amacı, sürdürülebilir kalkınma için kritik olan çevre dostu ve etkili doğasıyla Pompajlı Hidroelektrik Sistemlerinin (PHS) tasarımını kolaylaştırmak için kullanıcı dostu bir MATLAB GUI geliştirmektir.

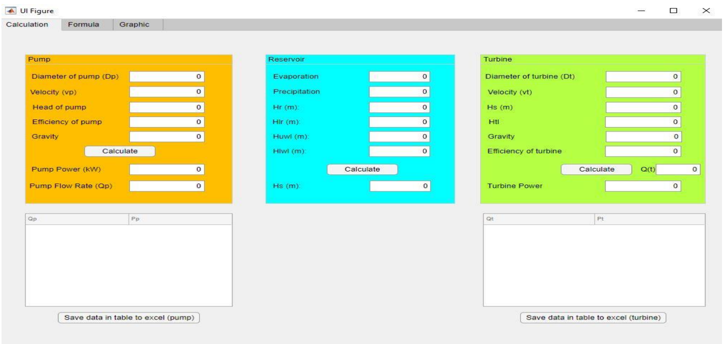

***Figure A:** PHS calculation interface / **Şekil A:** PHS hesaplama arayüzü*

Highlights (Önemli noktalar)

- *The study provides a MATLAB-based GUI that simplifies the design of PHS systems and accurately determines the fundamental components. / Çalışma, PHS sistemlerinin tasarımını basitleştiren ve temel bileşenleri doğru bir şekilde belirleyen bir MATLAB tabanlı GUI sunmaktadır.*
- *The research provides accurate simulations for the design of PHS systems, enhancing their real-world performance and efficiency. / Araştırma PHS sistemlerinin tasarımı için kesin simülasyonlar sunmakta ve bu sistemlerin gerçek dünya performansını ve verimliliğini artırmaktadır.*
- *This tool provides a practical and realistic solution for optimizing PHS system components, making it accessible to users without programming knowledge. / Bu araç, PHS sistemi bileşenlerinin optimize edilmesi için pratik ve gerçekçi bir çözüm sağlayarak, programlama bilgisi olmayan kullanıcılar için erişilebilir hale getirmektedir.*

***Aim (Amaç):** The aim of this study is to develop a user-friendly MATLAB GUI for designing PHS systems. / Bu çalışmanın amacı, PHS sistemleri tasarlamak için kullanıcı dostu bir MATLAB GUI geliştirmektir.*

***Originality (Özgünlük):** The study brings a new perspective to important works in the field while facilitating the design process for PHS systems with a MATLAB-based GUI. / Çalışma, PHS sistemleri için geliştirilen MATLAB tabanlı GUI ile tasarım sürecini kolaylaştırırken, alandaki önemli çalışmalara yeni bir bakış açısı getiriyor.*

***Results (Bulgular):** The developed MATLAB GUI offers a user-friendly experience by quickly and accurately calculating the essential components of PHS systems. / Geliştirilen MATLAB GUI, PHS sistemlerinin temel bileşenlerini hızlı ve doğru bir şekilde hesaplayarak kullanıcı dostu bir deneyim sunmaktadır.*

***Conclusion (Sonuç):** This study provides a practical and accessible solution for designing PHS systems using MATLAB GUI. / Bu çalışma, MATLAB GUI kullanımıyla PHS sistemlerin tasarımında pratik ve erişilebilir bir çözüm sunmaktadır.*

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Abstract

This research aims to create a user-friendly MATLAB Graphic User Interface (GUI) platform that can be used to design a Pumped Storage Hydroelectricity (PHS). The research highlights the environmentally friendly and effective nature of PHS systems, which are critical for sustainable development, especially in rapidly advancing developing countries. Introducing a user-friendly MATLAB GUI application aims to streamline the calculation of essential PHS design components, promoting accessibility for users without programming expertise. MATLAB GUI is a tool used to design user interfaces. It allows users to use the program interactively outside of the MATLAB command line, using graphical elements and can be associated with MATLAB codes. Thus, an interface design can be created quickly and effectively. The GUI developed as part of this research can define all the components required to create the PHS system and produce the same design specifications as those obtained through manual calculations. The GUI implementation gives the same result as the manually calculated design. The result obtained shows that the GUI interface works with high accuracy. As a result, it is thought that this model can be used in energy management applications, with the belief that this study will save valuable time and resources.

MATLAB GUI ile Pompalı Hidroelektrik Enerji Üretimini Tahmin Etmek İçin Hesaplama Aracı

Makale Bilgisi

Araştırma makalesi
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Anahtar Kelimeler

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Yenilenebilir Enerji

Öz

Bu araştırma, Pompalı Depolamalı Hidroelektrik (PHS) tasarımında kullanılabilecek kullanıcı dostu bir MATLAB Grafik Kullanıcı Arayüzü (GUI) oluşturmayı amaçlamaktadır. Araştırma, özellikle hızla ilerleyen gelişmekte olan ülkelerde sürdürülebilir kalkınma için kritik öneme sahip olan PHS sistemlerinin çevre dostu ve etkili yapısını vurguluyor. Kullanıcı dostu bir MATLAB GUI uygulamasının tanıtılması, temel PHS tasarım bileşenlerinin hesaplanmasını kolaylaştırmayı ve programlama uzmanlığı olmayan kullanıcılar için erişilebilirliği teşvik etmeyi amaçlamaktadır. MATLAB GUI, kullanıcı arayüzlerini tasarlamak için kullanılan bir araçtır. Kullanıcıların programı MATLAB komut satırı dışında grafiksel öğeler kullanarak etkileşimli olarak kullanmalarına olanak tanır ve MATLAB kodlarıyla ilişkilendirilebilir. Böylece hızlı ve etkili bir arayüz tasarımı oluşturulabilmektedir. Geliştirilen GUI, PHS sistemi oluşturmak için gereken tüm bileşenleri tanımlayabiliyor ve manuel hesaplamalarla elde edilenlerle aynı tasarım özelliklerini üretebiliyor. GUI uygulaması, manuel olarak hesaplanan tasarımla aynı sonucu vermektedir. Elde edilen sonuç GUI arayüzünün yüksek doğrulukla çalıştığını göstermektedir. Sonuç olarak bu çalışma değerli zaman ve kaynaklardan tasarruf sağlayacağı inancıyla bu modelin enerji yönetimi uygulamalarında kullanılabileceği düşünülmektedir.

1. INTRODUCTION (GİRİŞ)

The increasing interest in renewable energy sources and the growing challenges related to climate change have led to a growing need for energy storage and power management. Energy, a fundamental requirement for sustainable development, can drive industrialization and overall progress in societies if provided promptly, in sufficient quantities, under reliable economic

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conditions, and with low environmental impacts. In developing countries worldwide, energy demand is rapidly increasing in parallel with population growth, industrialization, and technological advancements [1, 2].

Hydroelectric Power Plants (HEPP) are renewable energy sources and, as such, do not produce any air pollutants or toxic waste, enhancing energy security and price stability. Hydroelectric power is a long-lasting electricity source with low operational and maintenance costs. While the initial investment cost for hydroelectric energy may seem relatively high, these projects have the lowest production costs and are not dependent on foreign capital and support when considering long-term economic assessments. Hydroelectric power plants utilize a country's fundamental national and renewable resources.

A Pumped Storage Hydroelectricity (PHS) system consists of two reservoirs designed to store electrical energy in the form of gravitational potential energy. Integral components include a pump and a hydro turbine. In times of higher electricity demand than supply, the system pumps water from the lower reservoir to the upper reservoir. Conversely, when electricity production falls below demand, stored water is released back to the lower reservoir through a hydro turbine, converting it into energy [3]. Given the inherent variability in energy production from renewable sources across different timeframes, stable power provision becomes a challenge. This underscores the crucial role of energy storage solutions. In this context, PHS emerges as a prominent and well-established method of large-scale energy storage technology [4]. PHS, commonly known as pumped hydro storage, plays a pivotal role in balancing electricity demand. The process involves utilizing surplus electricity during low-demand periods, typically at night, to pump water uphill into a reservoir. Subsequently, during high-demand periods in the day, the stored water is released downhill, generating electricity. Despite the additional energy required for uphill pumping at night, the strategic shift in electricity availability from nighttime to daytime imparts significant value [5].

To develop PHS systems that perform well in the real world, it is crucial to use a model that accurately simulates their performance. The size of components like flow rates, pumps, and turbines must be determined accurately for designing and implementing PHS systems. The more precise and accurate the model, the more practical and realistic the solution will be for achieving the optimal sizes of these components. To this end, a user-friendly Matlab Graphic User Interface (GUI) application has been developed that provides quick results for the basic components. MATLAB provides powerful tools for creating graphical user interfaces, allowing designers to create interactive applications that incorporate buttons, sliders, plots, and other graphical elements [6]. MATLAB GUIs are typically created using the GUIDE (Graphical User Interface Development Environment) or programmatically using MATLAB code. GUIDE is a MATLAB tool for designing GUIs visually. You can drag and drop components onto a canvas, set their properties, and define their callbacks using a point-and-click interface.

A GUI is an assemblage of interactive visual elements that empowers users to execute actions and access information within computer applications [7]. GUIs eliminate the need to remember specific commands, making it easier to learn and use operating systems. The advantage of GUIs is that users do not require any knowledge of programming languages. These operating systems are widely used in various sectors due to their user-friendliness and aesthetically pleasing appearance [8].

Extensive literature exists on MATLAB GUI; nevertheless, due to its distinctiveness, this study provides a concise literature overview of pertinent hydropower investigations. Notable studies in this context include the following: Wang and Qiu developed a MATLAB-based GUI to optimize sediment discharge and hydroelectric production in reservoirs [9]. Tiwari et al. scrutinized a hybrid plant through simulation modeling, delving into its chemical dynamics via Watpro 3.0 industrial software and investigating turbine management using MATLAB [10]. Tengberg, in his master's study, utilized MATLAB GUI for modeling the output power of a hydroelectric power plant and implementing an optimization algorithm [11]. Padmanadhan and Mohamad Nor, in their research, concentrated on creating a GUI for designing a mini hydroelectric power plant for the Pahang River in Temerloh. The GUI streamlines the design process by considering fundamental parameters like mass flow rate, netload, generator and turbine efficiency, and penstock size. The developed GUI effectively identifies component properties for establishing the mini hydropower system and yields results consistent with manually computed design specifications [8].

This research aims to develop a user-friendly interface that facilitates the calculation of various elements essential for designing a pumped-storage hydroelectricity system, ensuring ease of use and comprehension. The elements encompass power, flow rate, net head length, generator, and turbine efficiency. The article is organized as follows: (1) Materials and Methods, where the methods employed in the research, particularly the calculations associated with pumped storage hydroelectric power plants and the MATLAB GUI interface, are detailed. (2) Results and Discussion, where the research unveils and thoroughly elucidates the outcomes of the analysis, delving into their significance, implications, and potential applications. (3) Conclusion: The article concludes by summarizing the key findings and their relevance in the context of planning a PHS system. This structured approach helps the reader to understand the research better, guiding them through the study's various components and conclusions.

2. MATERIALS AND METHODS (MATERYAL VE METOD)

The GUI application was developed using MATLAB's App Designer environment after completing manual calculations. This stage is critical to ensure accurate results. This GUI consists of three sections: calculation, formula, and graphics (Fig. 1). The final application calculates the anticipated values for the design of a pumped hydroelectric power generation system.

The calculation section comprises three main categories: Pump, Reservoir, and Turbine. The pump's power required to pump water to the upper reservoir is calculated in the pump section. The volume of water to be collected is determined in the reservoir section. The turbine section calculates the net amount of energy to be produced by the system.

In this study, not all parameters required for PHS design are processed into the MATLAB GUI interface. Some necessary parameters (such as penstock, and evaporation) were calculated manually and entered into the system.

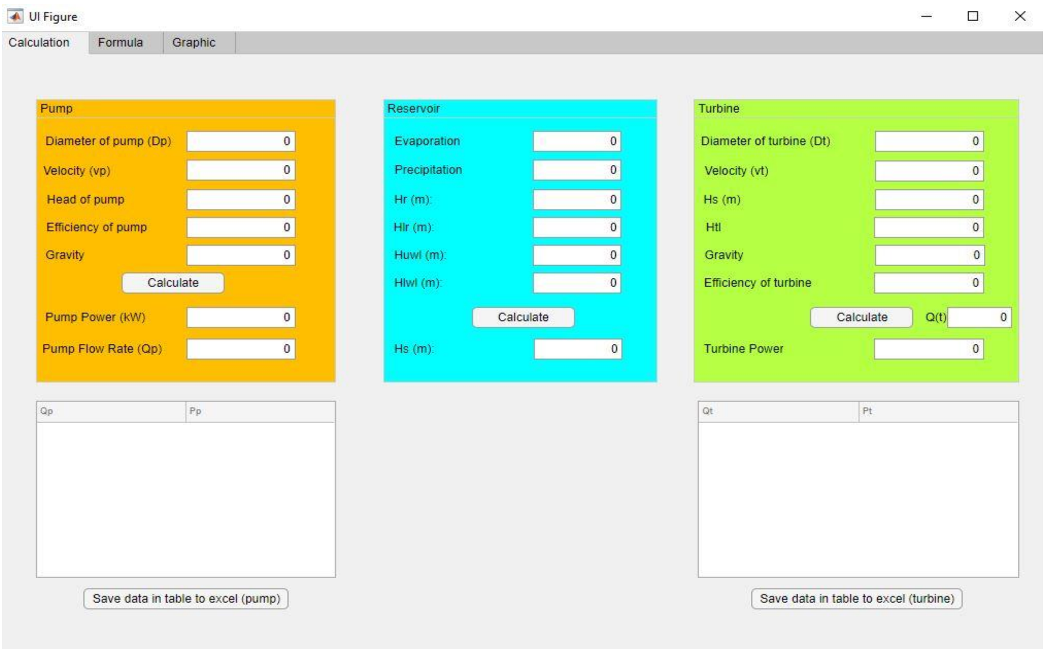

Figure 1. The calculation section (Hesaplama bölümü)

2.1. Structure of Interface (Arayüzün Yapısı)

2.1.1 Calculation Section (Hesaplama Bölümü)

The pump section is the first part of the calculation process, which is designed to determine the output power based on the physical data obtained from the installation site. This data includes the incoming flow rate, drop height, and pump efficiency. You can save the results of different variations in an Excel file located at the bottom of the pump section. The input mechanical power (P_p) of the pump can be calculated using the following equation [12]:

$$Q_p = \frac{P_p \eta_p}{\rho g H_p} \quad (1)$$

Equation (1) reveals that η_p (pump efficiency) is dependent on Q_p (pump flow rate (m^3/s)), with the efficiency-flow rate curve typically available in manufacturers' technical manuals. P_p is pump power (kW), ρ is the density of water (Kg/m^3), g is the acceleration due to gravity (m/s^2), and H_p is pump head (m).

Hp refers to the sum of static head (H_s) and head loss (H_{pl}) in pump mode (Equation 2).

$$H_p = H_s + H_{pl} \quad (2)$$

Hs represents the vertical distance between water levels in the upper and lower reservoirs. Hs, changes depending on the rise and fall of the water level during pumping and discharge of water. H_{pl} is affected by changes in Q_p and refers to hydraulic losses due to friction between water and the inner surface of the pipe and fittings.

$$H_{pl} = K\frac{v^2}{2g} \quad (3)$$

$$v = \frac{Q_p}{0.25\pi D_p^2} \quad (4)$$

$$K = K_{\text{pipe}} + K_{\text{fittings}} \quad (5)$$

$$K_{pipe} = \frac{fL_p}{D_p} \quad (6)$$

In the above equations (3-6); v^2 is the velocity (m/s), g is the acceleration due to gravity (m/s^2), D_p is the diameter of the pump pipe (m), f is friction factor (dimensionless), L_p is pipe length of the pump (m).

K refers to the total resistance coefficient of resistance encountered in the system. It consists of the sum of the resistance coefficients of the pipe (K_{pipe}) and additional parts ($K_{fittings}$). K_{pipe} specifically indicates the resistance coefficient of the pipe and is determined using Equation (6).

The penstock is responsible for directing water power to the turbine and reservoir, which are located at the bottom of the pipe. It's important to consider the penstock diameter and minimum wall thickness during the design process. The wall thickness of the penstock is determined by various factors, including the pipe material, tensile strength, pipe diameter, and operating pressure. Equations 7 and 8 outline the formulas used to calculate the penstock diameter [13-16].

$$D_e = 2.69\left(\frac{n^2Q^2L}{H_{net}}\right)^{0.1875} \quad (7)$$

$$t_{\min} = \frac{D_e + 508}{400} \quad (8)$$

Equation (7) shows that D_e is penstock diameter (m), n is the manning coefficient, Q is the flow rate (m^3/s), L is the length of penstock (m), and H_{net} is the net head (m). In equation (8), t_{min} is the minimum wall thickness (mm), and D_e is the penstock diameter (mm).

The reservoir section entails a model designed for estimating the volume of water stored in a reservoir. This model employs formulas that consider various factors, including inlet, outlet, and evaporation losses, operating under the assumption of zero leakage. The variables influencing these factors encompass temperature, relative humidity, net radiation, and wind speed. It is crucial to highlight that precipitation plays a significant role in the calculations, as it directly contributes water to the reservoir. Since the management of the system depends on the volume of stored water, precipitation volume ($\forall_{pre}$) and evaporation volume ($\forall_{eva}$) should be taken into account in the reservoir model.

$$\forall_{\text{eva}}(\Delta t) = \frac{ET}{3.6\times10^6}A\Delta t \quad (9)$$

$$\forall_{pre}(\Delta t) = \frac{I}{3.6\times10^6}A\Delta t \quad (10)$$

Equations (9-10) show ET is reference evapotranspiration (mm/hour), A is the area, I is precipitation (mm/h).

These calculations serve the purpose of determining both the water added to the reservoir and the resulting volume of stored water. By measuring water levels in the reservoir or obtaining data, Hs required for various calculations and analyses can be accurately calculated.

$$H_s = H_r + H_{uwl} + H_{lr} - H_{\text{lwl}} \quad (11)$$

In PHS systems, the water level in the lower reservoir (H_{lwl}) varies depending on the inflow and outflow of water. The input for the reservoir model is H_{lwl}. Moreover, the water level in the upper reservoir (H_{uwl}) can usually be calculated using a special equation based on the volume-area relationship of the reservoir. Here Equation (11) H_r refers to the vertical distance between the lower reservoir and the upper reservoir while H_{lr} is the height (inside) of the lower reservoir. Taking these factors into account ensures that the reservoir model accurately represents water levels in both the upper and lower reservoirs of the PHS system.

In this section, users manually input values for evaporation, precipitation, and H, following which the calculation button is utilized to determine the net height (H_s) required for energy production.

The turbine section provides details about the hydro turbine model and its correlation with the output power (P_t), flow rate (Q_t), and turbine head (H_t). The model computes the power output of the turbine, factoring in its efficiency (η). The turbine head (H_t)

is contingent on the loss of head between the upper reservoir and the turbine outlet, calculated using the Bernoulli equation. Moreover, the flow rate (Q_t) is influenced by the water levels in the reservoirs, with water velocity linked to parameters such as turbine valve opening and pipe diameter. Results from various configurations can be saved in an Excel file located at the turbine section's bottom. The turbine output power generally (P_t) can be determined using the following equation [17]:

$$P_t = Q_t H_t \rho g \eta_t \tag{12}$$

The efficiency of the turbine, generator, and transformer (η_t) is a multiplier for the head (H_t). H_t is defined as the difference between the head loss (H_{tl}) between the reservoir and the turbine outlet and the vertical head (H_s) between the water levels in the upper and lower reservoirs. The flow rate (Q_t) is contingent on the water levels present in the reservoirs.

The turbine serves as a mechanism that transforms water pressure into mechanical energy, which can subsequently be harnessed to drive an electric generator or other electrical devices. This conversion unfolds through two primary stages. Initially, the fluid dynamic power inherent in the water is transformed into mechanical energy. Subsequently, this mechanical energy undergoes conversion into electrical energy [4]. Turbine-type recommendations should be selected by using turbine manufacturers' tables.

2.1.2 Formula Section (Formül Bölümü)

Figure 2 displays the formulas utilized in the user's initial calculation tab. This tab explains in detail how to calculate the design parameters, specifying the formulas used in these calculations. This method intends to provide the user with an opportunity to learn and comprehend the mathematical principles behind the system.

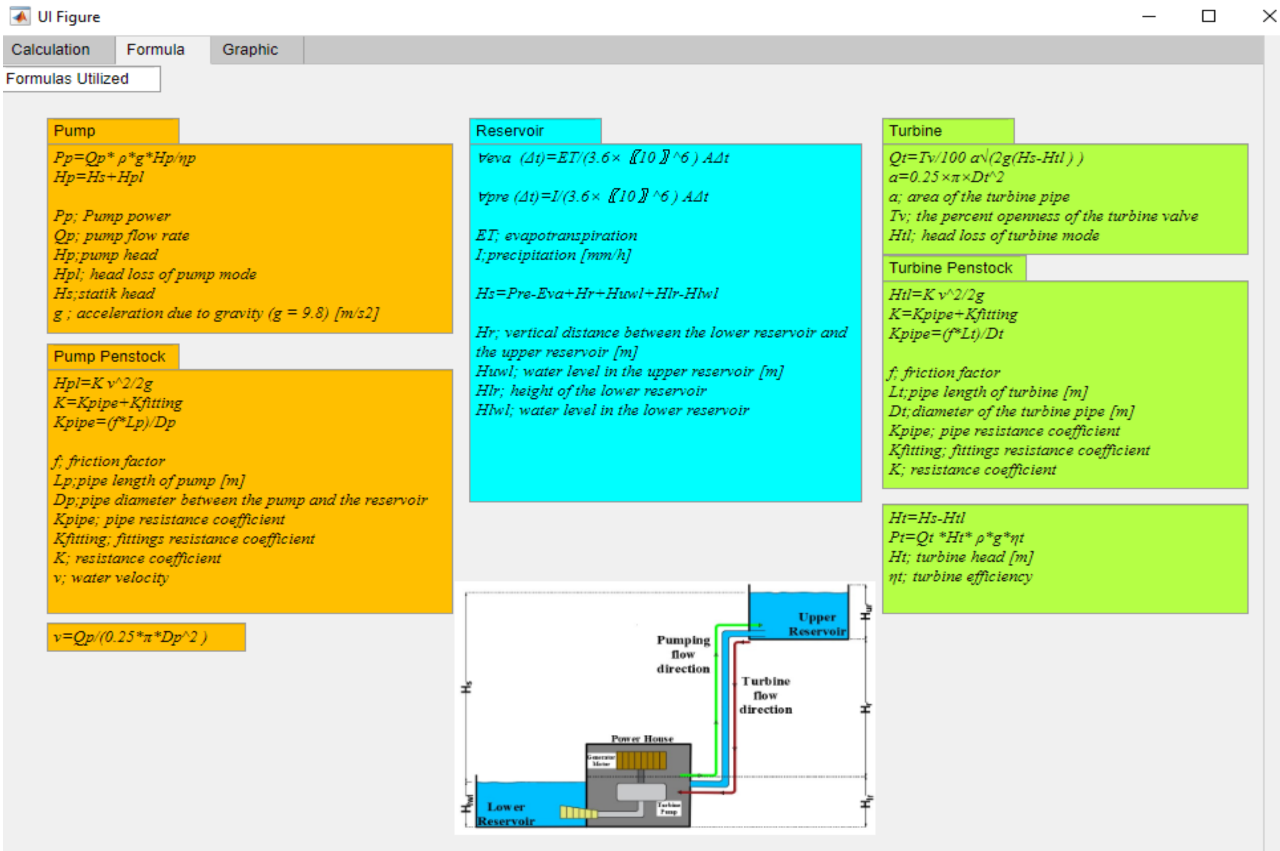

Figure 2. The formula section (Formül bölümü)

2.1.3 Graphic Section (Grafik Bölümü)

The Graph tab in Figure 3 graphically shows the relationship between pump and flow rate and turbine and flow rate. When the plot buttons on the tab are clicked, the graphs of the relevant relationships are displayed. This will help the user gain insight into the pump and turbine efficiency of the model because the graphs clearly show the relationship between flow rate and efficiency.

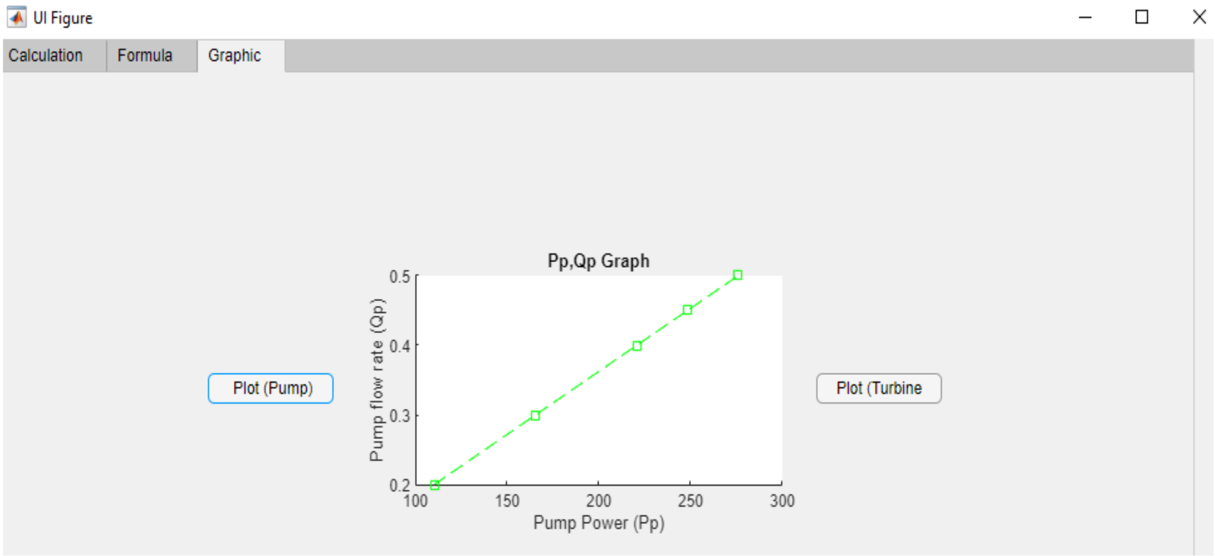

Figure 3. The graphic section (Grafik bölümü)

3. RESULTS AND DISCUSSION (Sonuçlar ve Tartışma)

This section delves into manual and MATLAB GUI calculations employed in designing a pumped hydroelectric power plant. These calculations were executed by collecting data from reliable sources. The design assumed a constant output power of 1 MW and above. The design scenario was formulated based on the information presented in Table 1, which was instrumental in estimating the design parameters.

Table 1. PHS design parameters (PHS dizayn parametreleri)

Item	Value		
	Pump	**Reservoir**	**Turbine**
Flow rate (m^3/s)	1.5	--	2.0
Output power (kW)	2,052.34	--	1,000 kW
Evaporation (m)	0.007	0.007	--
Precipitation (m)	0.5	0.5	--
The vertical distance between the lower reservoir and the upper reservoir (H_r) (m)	60	60	60
Height of the lower reservoir (H_lr) (m)	60	60	--
Water level in the upper reservoir (H_{uwl}) (m)	20	20	--
Water level in the lower reservoir (H_{lwl}) (m)	50	50	--
Efficiency of turbine (%)	--	--	90
Length of penstock (m)	100	--	100
Type of pipe	Steel	--	Steel

The MATLAB GUI app calculates the pump power to pump the determined flow up based on the vertical equation (1). When calculating pump power, the diameter and wall thickness of the penstock are critical parameters. This is an important factor affecting the cost of determining optimal penstock dimensions. For this purpose, Equations (7) and (8) were used to achieve the desired power. Additionally, the Manning roughness coefficient (f) for stainless steel is accepted as 0.010. [18, 19]

The output power of the penstock was calculated using Equation 7 and Equation 8 for the penstock diameter and minimum wall thickness. After performing calculations manually and using MATLAB GUI, the value of P_t was determined to be 1174.45 kW through manual calculations and 1174.5 kW using the MATLAB GUI. The negligible difference between the two results confirms the proper functioning of the MATLAB GUI. Furthermore, Padmanadhan and Nor have also confirmed the similarity of these values in their mini hydropower MATLAB GUI [8].

The pumped storage project features an existing lower reservoir, either natural or constructed. Daily operations of the project encompass both electricity generation and water pumping into the upper reservoir, with both processes occurring on the same day. Under favorable operating conditions of the lower reservoir, pumping water to the upper reservoir does not impact the lower reservoir's water level. The reservoir model takes into account inflow, outflow, and evaporation losses to estimate the water volume stored in the upper reservoir, assuming zero leakage. As reservoirs typically have an open upper surface, precipitation can raise water levels, while evaporation can decrease them. The evaporation amount is influenced by factors such as temperature, relative humidity, net radiation, and wind speed from the water surface. Precipitation volume varies based on average annual precipitation in climatic regions. To ensure accurate energy management system calculations, both precipitation and evaporation volumes should be integrated into the reservoir model. In our case, as these values were not incorporated into the developed MATLAB GUI application, we manually calculated them and entered the results into the application. In addition, these values were obtained from the General Directorate of Meteorology in Turkey.

The hydro turbine unit plays a pivotal role in converting stored energy into mechanical energy, propelling the rotation of the shaft connected to the generators. The turbine model outlines the process through which kinetic energy transforms electrical energy, establishing the correlation among output power (P_t), flow rate (Q_t), and turbine load (H_t). Turbine efficiency (η) signifies the power loss within the turbine due to mechanical and electrical losses and delineates the proportion transformed into electrical energy. In turbines, efficiency (η) is contingent upon the flow rate (Q_t), and manufacturers furnish an efficiency-flow curve for each turbine, illustrating its performance under specific operating conditions. The overall efficiency of a pumped storage system typically ranges between 75% and 80% [20]. Finally, this section necessitates the selection of the penstock diameter and thickness, mirroring the requirements of the pump section.

The power output of the penstock has been computed using Equation 7 and Equation 8, taking into account the diameter and minimum wall thickness of the penstock. Table 2 juxtaposes the results obtained from manual calculations employing three distinct variables alongside their corresponding outcomes from the MATLAB GUI. To maintain consistency, the analysis maintained constant values for evaporation and precipitation at 0.007 and 0.5 m, respectively, across all scenarios. The turbine efficiency remained steadfast at 90%, assuming consistent turbine performance. However, it's noteworthy that the optimal turbine selection can be made by scrutinizing the graphics provided by turbine manufacturers.

The analysis delves into diverse operational scenarios by manipulating the vertical distance between the lower and upper reservoirs (H_r), the height of the lower reservoir (H_{lr}), and the water levels in both reservoirs (H_{lwl} and H_{uwl}). These variations in the variables reflect distinct operational conditions or scenarios. Three different scenarios are examined in Table 2. These scenarios include upper and lower reservoir volumes, water level heights, and penstock length factors. Changes in upper reservoir volume and upper reservoir water level result in changes in static pressure (Hs). Changes in H_s affect the powers of the pump and turbine. Therefore, different values in Table 2 were used to understand the changes that may occur in the system.

Upon examining Table 2, it is evident that manual calculations and the computational tool in MATLAB GUI yield different pump and turbine output power results for various scenarios. The values vary according to changes in system parameters. It is observed that altering the length of the penstock (80 m, 90 m, 120 m) leads to changes in the power generated. This demonstrates the significant impact of penstock dimensions on the system and underscores the importance of maintaining the structural integrity of the penstock. Overall, the table illustrates how input parameters influence the calculated pump power and output power, with manually calculated results differing negligibly from those in the MATLAB GUI.

Table 2. Manual and MATLAB GUI results obtained with different values (Farklı değerlerle elde edilen Manuel ve MATLAB GUI sonuçları)

Item	Manual result			GUI result		
Evaporation (m)	0.007	0.007	0.007	0.007	0.007	0.007
Precipitation (m)	0.5	0.5	0.5	0.5	0.5	0.5
The vertical distance between the lower reservoir and the upper reservoir (H_r)	20	40	80	20	40	80
Height of the lower reservoir (H_{lr}) (m)	60	60	60	60	60	60
Water level in the lower reservoir (H_{lwl}) (m)	30	40	50	30	40	50
Water level in the upper reservoir (H_{uwl}) (m)	20	20	20	20	20	20
Length of penstock (m)	80	90	120	80	90	120
Efficiency of turbine (%)	90	90	90	90	90	90
Penstock diameter (m)	0.635	0.633	0.63	0.635	0.633	0.63
Penstock min wall thickness (mm)	2.85	2.85	2.85	2.85	2.85	2.85
Pump power (kW)	1665.2	1859.182	2437.5	1665	1859.2	2437.6
Output power (kW)	841.21	1006.1	1510.2	841.18	1006.1	1510.1

4. CONCLUSIONS (SONUÇLAR)

The outcomes reveal that the MATLAB GUI application adeptly computes the output power for the pumped hydropower system with precision. The instructional value of the MATLAB GUI application is evident in its demonstration of formula utilization within the design phase, offering a valuable learning experience. Nearly all sizing techniques and formulas relevant to PHS have been seamlessly incorporated into the MATLAB GUI. Nevertheless, within the MATLAB GUI framework, it is essential to formulate losses, such as precipitation and evaporation, for any manually inputted values of these parameters, ensuring the development of a pertinent design proposal.

This simulation serves as a foundational illustration, necessitating potential tailoring to align with the specific requirements of your hydropower calculations. It is advisable to contemplate the inclusion of error-handling mechanisms, unit considerations, and additional functionalities based on the specific context. Importantly, one should bear in mind that the actual hydropower calculation formula might entail heightened complexity contingent upon the distinctive characteristics of your hydropower system, thereby necessitating the corresponding adjustment of the available code snippets.

As a result, manually calculated PHS system calculations show that a more practical model gives faster and more accurate results. However, while it is recommended to use this model in energy management applications, it is thought that accelerating future work will save valuable time and resources.

NOMENCLATURE (Terminoloji)

A	Area
D_e	The Penstock diameter (m)
D_p	The pipe diameter (m)
ET	Evapotranspiration (mm/hour)
f	Friction factor (dimensionless)
GUI	Graphic user interface
G	Acceleration due to gravity (m/s^2)
H_p	Head of the pump mode (m)
H_s	The sum of the static head (m)
H_t	Head of the turbine mode (m)
H_{pl}	Head loss of the pump mode (m)
H_r	Vertical distance between the lower reservoir and the upper reservoir (m)
H_{uwl}	Water level in the upper reservoir (m)
H_{lr}	Height of the lower reservoir (m)
H_{lwl}	Water level in the lower reservoir (m)
H_{tl}	Head loss of the turbine mode (m)
I	Precipitation (mm/h)
K	Resistance coefficient (dimensionless)
K_{pipe}	Pipe resistance coefficient (dimensionless)

$K_{fitting}$ Fittings resistance coefficient (dimensionless)

L_p Pipe length of the pump penstock (m)

L Length of the penstock (m)

PHS Pumped storage hydroelectricity

P_t Output power (kW)

P_p Pump power (kW)

Q_p Pump flow rate (m^3/s)

Q_t Turbine flow rate (m^3/s)

T_v The percent openness of the turbine valve (%)

v Water velocity (m/s)

t_{min} Minimum wall thickness (mm)

η_p Pump efficiency (%)

η_t Turbine efficiency (%)

ρ Density of water (Kg/m^3)

DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Aysenur OYMAK, Ibrahim Halil DEMİREL ve Mehmet Rıda TÜR*:** The authors contributed equally to this study.

Bu çalışmada yazarlar eşit katkı sağlamıştır.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

REFERENCES (KAYNAKLAR)

[1] Yılmaz A O. Renewable energy and coal use in Turkey. Renewable Energy. 2008; 33: 950–959. https://doi.org/10.1016/j.renene.2007.04.022.

[2] Dal A R. Investigation of the potential of using lakes and dams as solar power plants: The case of Yamula Dam. Gazi University Journal of Science Part C: Design and Technology. 2021; 9(4): 726-738. https://doi.org/10.29109/gujsc.1002791.

[3] Wang W, Li C, Liao X, Qin H. Study on unit commitment problem considering pumped storage and renewable energy via a novel binary artificial sheep algorithm. Applied Energy. 2017; 187: 612–626. https://doi.org/10.1016/j.apenergy.2016.11.085.

[4] Cetinkaya S. (2014). Capacity Determination of Pumped Storage Projects Using Market Electricity Prices. Master Thesis, The Graduate School of Natural and Applied Sciences of Middle East Technical University, Ankara, Turkey.

[5] U.S. Energy Information Administration. Electricity Storage Can Take Advantage of Daily Price Variations. [Accessed: 18 Oct-2013]. http://www.eia.gov/todayinenergy/detail.cfm?id=6350.

[6] Math Works Inc. (2000–2015). MATLAB® Creating Graphical User Interfaces.

[7] Hope C. What is a GUI (Graphical User Interface)? 2021. Computerhope.com. [Accessed: 03- Apr- 2021]. https://www.computerhope.com/jargon/g/gui.htm.

[8] Padmanadhan P. V. M. and Mohamad Nor A F. A graphical user interface (GUI) based method for designing a mini hydro-power. Evolution in Electrical and Electronic Engineering. 2022; 3 (1): 089–096. https://doi.org/10.30880/eeee.2022.03.01.011.

[9] Li F F, Wang H R, and Qiu J, A MATLAB GUI program for reservoir management to simultaneously optimize sediment release and power generation. Journal of Environmental Management. 2022; 320:115686.

[10] Tiwari J, Singh AK, Yadav A, Jha R K. Modelling and simulation of hydro power plant using matlab &watpro 3.0. International Journal of Intelligent Systems and Applications. 2015; 7(8): 1-8. https://doi.org/10.5815/ijisa.2015.08.01.

[11] Tengberg O. Mechanical Engineering, master's level. Luleå University of Technology Department of Engineering Sciences and Mathematics. 2019.

[12] Mousavi N, Kothapalli G, Habibi D, Khiadani M, K Das C. An improved mathematical model for a pumped hydro storage system considering electrical, mechanical, and hydraulic losses. Applied

Energy. 2019; 247: 228-236. https://doi.org/10.1016/j.apenergy.2019.03.015
[13] Adejumobi IA, and Adebisi OI, Exploring small hydropower potentials for domestic and information communication technology infrastructural application in rural communities in Nigeria. 2011 Proceeding of the 12th Biennial International Conference of Botswana Institution of Engineers, 19-26.
[14] Adejumobi, IA, and Adebisi, OI, Equipment Selection for a Sustainable Small Hydro Power Scheme. 2011 Top Research Group Conference, Lome, Togo.
[15] M K Singhal, and Kumar A. Optimum design of penstock for hydro projects. International Journal of Energy and Power Engineering.2015; 4(4): 216. https://doi.org/10.11648/j.ijepe.20150404.14.
[16] B. Nasir. Design considerations of micro-hydro-electric power plant. Energy Procedia. 2014; 50: 19-29. https://doi.org/10.11648/j.ijepe.20150404.14.
[17] Yuksel I, and Demirel I H. Investigation of the optimal method for determining hydropower potential of small streams: a case study Batman Basin in Turkey. Arab J Geosci, 2021;14: 580. https://doi.org/10.1007/s12517-021-06877-y.
[18] Altınbilek D, Bozkuş Z, Gögüs M, Aydın İ, Ger M, Önder H, ... Sakarya B. CE 372 Hydromechanics Lectures Notes. 2006; Ankara: METU Press.
[19] Potter M C, and Wiggert D C. (2002). Mechanics of Fluids (Third ed.). California: Brooks/Cole.
[20] Zipparro V J, and Hasen H. (1993). Davis' Handbook of Applied Hydraulics (4 ed.). New York: McGraw Hill.