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Research Article

Optimum Energy Production in Hydroelectric Power Plants

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Abstract

In this study, it is aimed to obtain the highest energy that can be obtained from hydroelectric power plants (*HEPP*) by providing minimum water consumption. Accordingly, with the Particle Swarm Optimization (*PSO*) method applied according to the characteristics of the plants specified in the study (***Atatürk, Karakaya, Keban, Altınkaya and Deriner***), the highest electricity production capacities that can be produced from the plants were obtained by reaching the optimum flow rate, water consumption value from the MATLAB/Simulink model diagrams. The best solution obtained according to the PSO algorithm method is presented in terms of global best (**G_{best}**), particle best (**P_{best}**) energy production and water consumption. Energy production and target function values (fitness) for each flow rate range were tried to be determined pointwise. As a result, existing or new HEPP's to be established should be provided with a balance between energy production and water consumption, sustainable, well-manageable and more efficient.

Keywords: Particles swarm optimization, Hydroelectric power plant, Energy, Efficiency, Matlab.

Hidroelektrik Santrallerde Optimum Enerji Üretimi

Öz

Yapılan bu çalışmada, hidroelektrik enerji santralinden (HES) elde edilebilecek en yüksek enerjiyi minimum su sarfiyatı sağlayarak elde edilebilmesi amaçlanmıştır. Buna göre çalışma içerisinde belirtilen santral (***Atatürk, Karakaya, Keban, Altınkaya ve Deriner***) özelliklerine göre uygulanan Parçacık Sürü Optimizasyon (Particul Swarm Optimization-PSO) yöntemiyle, Matlab/Simulink model diyagramlarından optimum debi yani su tüketimi değerine ulaşılarak santrallerden üretilebilecek en yüksek elektrik üretim kapasiteleri elde edilmiştir. PSO algoritma yöntemine göre elde edilen en iyi çözüm global en iyi (**G_{best}**), parçacık en iyi (**P_{best}**) enerji üretimi ve su tüketimi açısından optimize edilmiş değerler sunulmuştur. Her bir debi aralığı için enerji üretimi ve hedef fonksiyon değerleri (*fitness*) noktasal olarak belirlenmeye çalışılmıştır. Sonuçta var olan veya kurulacak olan yeni HES'lerin enerji üretimi ve su sarfiyatı arasında bir denge olacak şekilde, sürdürülebilir iyi yönetilebilirliği ve daha verimli olması sağlanmalıdır.

Anahtar Kelimeler: Partikül sürü optimizasyonu, Hidroelektrik santral, Enerji, Verimlilik, Matlab.

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1. Introduction

Energy is an indispensable building block in life and in the modern world. Humans need energy to sustain their lives. It has an important place in many sectors that affect human life, such as transportation, health, and industry. It is thought that it will be important to meet the energy need from sustainable and renewable sources, which will also be valid for future generations. Therefore, how to use the existing water reserve areas in the most effective way and how to produce maximum electricity from them is important in hydroelectric energy production. Because the efficient use of water resources is important in terms of increasing the performance of the power plant with the improvements to be made and minimizing energy production costs. As a clean and sustainable energy source, hydroelectric power plants are seen as a preferred renewable energy source due to Türkiye's geographical structure and favorable climate conditions.

It is considered that increasing the efficiency of existing and newly established hydroelectric power plants in Türkiye and the world is strategically valuable in terms of energy production, economic return and sustainable development. Studies on the efficiency of hydroelectric power plants and energy resources have been increasing in recent years.

The potential of hydraulic resources is in question in our country, with many environmental and economic benefits that cannot be underestimated. It is stated that such power plants have many advantages such as controlling floods and inundations, maintaining the balance of water supply and demand, low carbon emissions and environmental effects, ready energy, low maintenance and operating costs. It is thought that importance and priority should be given to energy policies and the problems that will hinder the development of energy policies should be eliminated. Legal procedures and power plant operating activities have shown that they are important, especially in the establishment and commissioning of small power plants that are considered to have significant investment potential [1].

In another study, energy production costs and production quantities were evaluated as a result of examining 10 hydroelectric power plants used for electricity production with various analysis methods in terms of efficiency. In the evaluation, it was stated that the inputs in HEPPs were not independent from the dam storage areas [2].

It is thought that hydroelectricity has an important share among renewable energy sources for all countries in the world. It has been stated that Turkey has the greatest potential in Europe in terms of hydroelectric potential. It has been stated that studies are being carried out to increase the efficiency of hydroelectric power plants in Turkey, in advanced technologies and other areas, and to reduce the effects of environmental negativities. It is stated that in order to close the energy deficit targeted by hydroelectric power plants in Turkey, it is important to spread independent individual consumption in households with small-scale hydroelectric power plants [3]. In the study, 51 hydroelectric power plants currently installed in Turkey The energy efficiency of the power plant was examined with various modeling methods and as a result, it was stated that the power plants were operated at an efficiency rate of 19%. [4].

They proposed a new mathematical modeling while considering the energy production problem for a short-term hydroelectric power plant unit in a multi- reservoir system with a cascade-based operation scenario. To solve the problem, the optimization method multi-objective evolutionary swarm hybridization (MESH) approach was applied. In a realistic problem, they compared it with evolutionary approaches based on solution search methods within algorithms such as NSGA-II, NSGA-III, SPEA2 and MOEA/D. In the projection analysis performed, it was stated that the MESH approach exhibited superior performance than multi-objective alternative approaches in terms of efficiency and accuracy [5].

In the study, it is mentioned that hydroelectric power plants are among the first renewable energy sources for Turkey as a renewable and sustainable energy source. It is mentioned that investments should be increased in order to prevent environmental problems and avoid economic losses caused by fossil fuel use in countries [6].

In the study, the hydrographic data of the streams in the riverbeds of some provinces in the Black Sea region and the turbine speed numbers and specific speed values of the hydraulic power plant operations were calculated. It was claimed that these calculations allowed turbine selection and comprehensive analysis. According to the results of the study, it was stated that the net head had a decisive effect on the specific speed [7].

The common purpose of the studies carried out for this purpose is to increase energy production to higher levels within hydroelectric power plants with different production capacities in large, small, mini and micro scales and to operate in a sustainable manner. For this reason, a study was carried out on the evaluation of energy production according to the optimum flow and net head values that can be obtained based on sustainability and efficiency in hydroelectric power plants.

According to the latest data published by TEİAŞ on February 17, 2025 [8], Turkey's daily electricity production rates from renewable energy sources, including unlicensed, are shown in the graph below in Figure 1. As can be seen from the graph, Turkey's share in electricity production from renewable energy sources is 26% with 44,095 MWh. The energy source with the largest share here is thermal power plants with 62% with 27,214 MWh. This is followed by solar, hydraulic, hydraulic, wind and other sources. The share of hydraulic energy in electricity production is 12% with 5440 MWh.

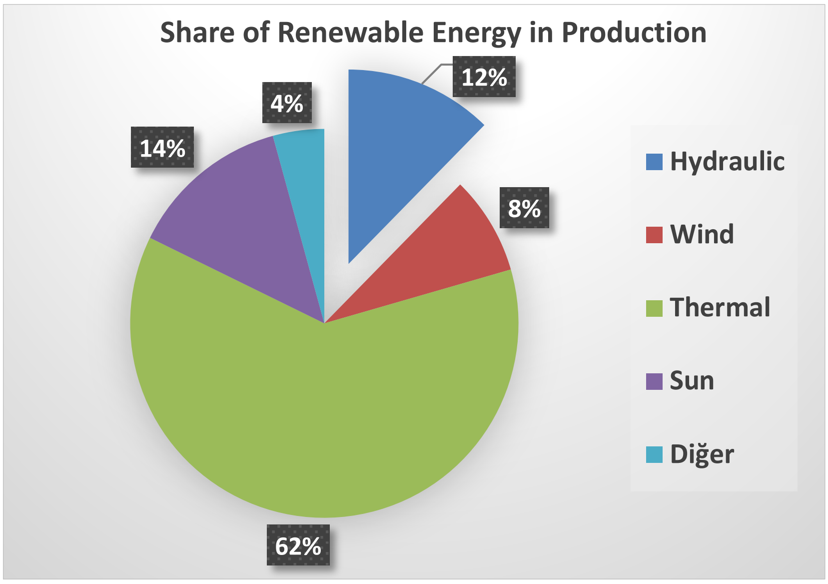

Figure 1 Electricity Production in Turkey [8].

The advantages of hydroelectric power plants are that they do not pollute the environment, they can be stored, they contribute to efficient and less consumption of water, agricultural irrigation needs, electricity production, and energy production with hydroelectric power plants as sustainable and clean energy has an important place among renewable energy sources. The density map of hydroelectric power plants used as energy sources in Turkey is given below in Figure 2. Figure 2 shows power plants that are mostly established in the central and eastern Black Sea regions and the eastern and southeastern Anatolia regions.

Figure 2. Turkey HEPP Installed Power Density Map [9].

In Figure 3 below, monthly hydroelectric production data for 2024 is shown in GWh. In the given graph, it is seen that production gradually increases towards the summer months such as March, April and May, and gradually decreases towards the winter months after July. In this graph, it is understood that there are differences in production amounts due to seasonal differences.

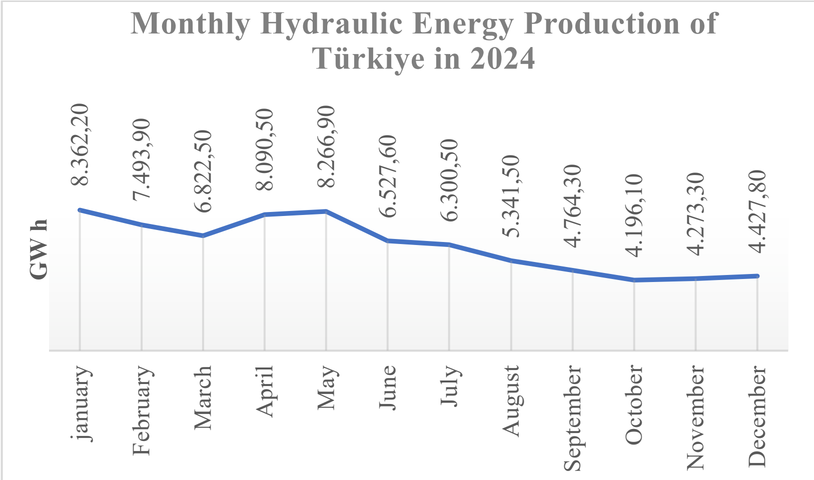

Figure 3. Monthly Distribution of Türkiye's Gross Electricity Production in 2024 by Hydroelectric Energy Source [10].

The following Table 1 shows the installed power values of the top 10 Hydroelectric Power Plants (HES) in Türkiye. The Atatürk Dam ranks first in the table with 2,405 MW of power.

Table 1 The 10 Largest Hydroelectric Power Plants in Turkey [11].

Q.	Central Ordinary	City	Installed Power (MW)
1)	Atatürk Dam and HPP	Şanlıurfa	2,405
2)	Karakaya the Dam HPP	Diyarbakır	1,800
3)	Keban the Dam and HPP	Elazığ	1,330
4)	Ilısu the Dam and HPP	Mardin	1,209
5)	Altınkaya the Dam and HPP	Samsun	703
6)	Birecik the Dam and HPP	Şanlıurfa	672
7)	Deriner the Dam and HPP	Artvin	670
8)	Yukarı Kaleköy the Dam and HPP	Bingöl	627
9)	Beyhan the Dam and HPP	Elazığ	582
10)	Yusufeli the Dam and HPP	Artvin	548

Among these power plants, the change in the amount of energy production over the months is shown graphically in Figure 4, considering the 2024 data on the efficiency of the Atatürk, Karakaya, Keban, Altınkaya and Deriner dam energy production plants according to their production power capacity.

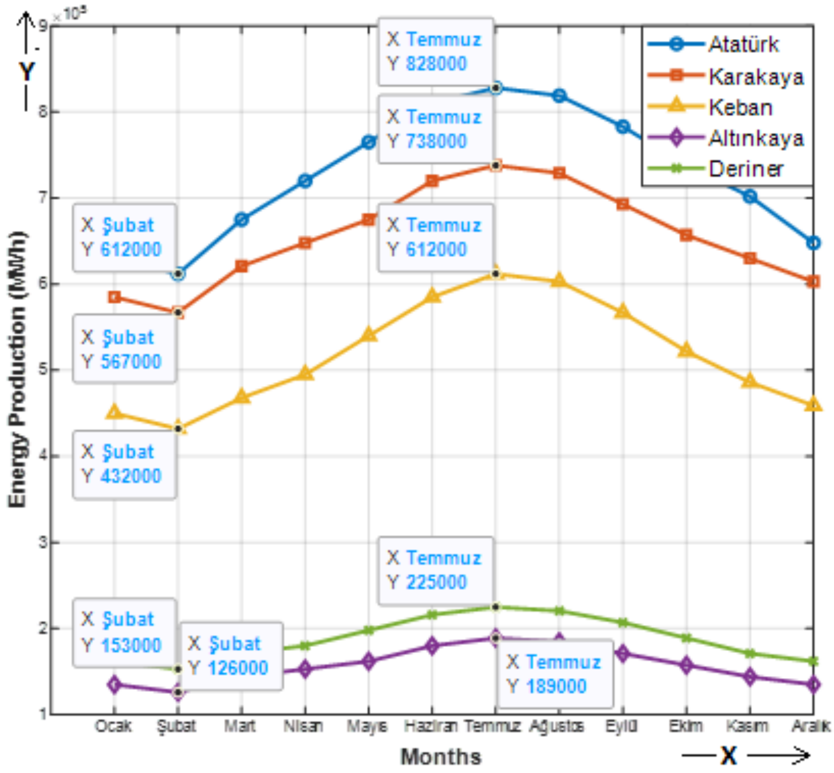

Figure 4. Monthly Energy Production Graph of the specified power plants in 2024 [10].

The graph in Figure 4 is examined, the monthly energy production values of 2024 are at their lowest levels in January, February, November and December. The reason for this is that the rainfall in the winter season is low and the water flows at a low flow rate. As a result of the increase in rainfall and the increase in water level between February and July, the amount of energy production gradually increases and reaches the upper value. It is seen that the amount of energy production gradually decreases between July and November due to the decrease in rainfall and high-water consumption.

Again, as seen from the same graph, according to the July data, the highest energy production was realized in the Atatürk (HEPP) dam with 828,000 MWh and the lowest energy production was realized in the Altınkaya (HEPP) dam with 189,000 MWh. In this research, Atatürk, Karakaya, Keban, Altınkaya and Deriner hydroelectric power plants Detailed information and plant features are given separately in Table 2 below.

Table 2. Ataturk, Karakaya, Keban, Altınkaya and Deriner HEPP Technical Data Table [13].

Central Features	**Hydroelectric Power plants (*HEPP*)**				
	Ataturk	**Karakaya**	**Keban**	**Altınkaya**	**Deeper**
Location	Sanlıurfa	Elazığ	Tunceli	Samsun	Artvin
Dam Type	Rock fill	Concrete belt	Rock and concrete	Rock fill	Concrete belt
Body Height (meter)	169	158	207	195	249

Body Volume (million m³)	84.5	4.5	16	15.9	3.5
Storage Volume (billion m³)	48.7	9.58	31	5.8	1.97
Unit Number of	8	6	8	4	4
Each Unit Power (MW)	300	300	165	175	167.5
Annual Electric Production (billion kWh)	8.9	7.5	6	1.6	2.1
Goal Area (km²)	817	268	675	118	26.4
Building the Beginning	1983	1976	1966	1983	1998
Date of Commissioning	1992	1987	1974	1988	2012
Productivity	0.9	0.9	0.9	0.9	0.9
Useful Height (m)	160	126	175	180	207
Maximum Flow(m³/s)	5100	2,200	1920	1800	1,100
Minimum Flow(m³/s)	70	60	176	150	15
Energy production weight (α)	0.7	0.7	0.7	0.7	0.7
Su tüketim ağırlığı**(β**)	0.3	0.3	0.3	0.3	0.3

According to the values given in Table 2, the production process and cost analyses of the five different hydroelectric power plants were handled according to the determined optimization method. In this table, body height (distance from ground to top) and useful height (distance between turbine and peak) optimization techniques aim to determine the values that will provide the highest energy production and the lowest water consumption from the hydroelectric power plant. There are many optimization techniques (methods) applied in power systems to estimate these targeted optimum values. Some of these mathematical models and optimization algorithms are:

PSO (Particle Swarm Optimization) for optimized economic load distribution, Genetic Algorithms (GA) for economic load distribution, production planning and renewable energy optimization, Simulated Annealing (SA) for load distribution, network design and optimal energy distribution, Gradient - Based Methods for energy production and distribution, load flow calculations. Methods), Decision Trees and Artificial Neural Networks (ANN) for demand forecasting and energy production as well as fault prediction and maintenance, Tabu Search for energy flow optimization and generator placement , Differential Evolution (DE), Hydraulic modeling (CFD - Computational Fluid Dynamics) behavior of water inside the turbine, Brainstorming and Swarm Simulation for energy management and network improvement There are types of optimization used in power systems such as Intelligence [12].

With these mathematical methods, the movement of water from the dam basin until it leaves the turbine wheel can be monitored in real time according to operating parameters and the turbine speed can be controlled. While instantaneous analyses are performed, thanks to the developed program and algorithms, the transfer and distribution of the produced and stored energy to the intercollective system, cost analysis, sustainability, efficiency and manageability are effectively optimized. Some recent studies on the use of PSO in mathematical models and optimization algorithms of hydroelectric power plants are as follows:

In the study conducted on the use of PSO, a study was conducted to minimize the risks of floods, inundations and inundations that may occur under hydrological and meteorological conditions, and to maximize the income that can be obtained from a hydroelectric power plant. It is stated as preliminary information that superior performance results were obtained compared to other applications mentioned in the study as a result of the integration of the particle swarm optimization (PSO) algorithm into the neural network of the existing controller system in the power plant. It is thought that the integration of satellite data for interaction with changes in meteorological or other climatic and environmental conditions in this integration process can contribute to optimum energy production [15].

In another study, it is mentioned that there are decreases in efficiency due to hydrological effects and fluid water delays affecting the performance in hydroelectric power plants. In the study, performance evaluation was made on different examples with mixed integer linear programming (MILP) and particle swarm optimization (PSO) methods. It is mentioned that when there are two units in a hydroelectric power plant, the values obtained from MILP are optimum and better performance values are obtained than PSO results. However, it is mentioned that PSO scales better and performs better when there are 6 units in the power plant. It is mentioned that the methods mentioned here can produce relative results due to limited data inputs [16].

In the study, research was conducted on the maintenance costs of the power plant and the improvement of the maintenance program. A new equation model was proposed for the purpose of application in Small-Scale Hydroelectric Power Plants. This proposed equation model is called Chaos Embedded Adaptive Particle Swarm Optimization (CEAPSO) and consists of 4 terms and 7 parameters. The improvements in maintenance costs according to the method used are mentioned [17].

Joski et al. aimed to develop load frequency control for Proportional–Integral–Derivative (PID) controllers in hydroelectric power plants in their study. Particle swarm optimization (PSO), Fuzzy logic, hybrid and fuzzy optimization methods were examined based on the differences created by the frequency and power oscillation graphs of the controller specified in the study. It was stated that the optimization process applied as Fuzzy-PSO-PID provided more advantageous dominance compared to other comparisons [18].

In the study, a comparison was made for the costs of an independent power system under different optimization methods and their effects on the power system. As a result of the application of Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Gray Wolf Optimization (GWO) techniques, it is claimed that GA makes calculations in a shorter time compared to GWO and PSO in calculating the cost of an independent hybrid system. It is thought that the GA method will be beneficial against annual system costs, especially in systems where grid connection cannot be reached [19].

In the study, the importance of obtaining quality energy as a result of power control in hydroelectric power plants was mentioned. Quality energy means obtaining constant voltage and constant power for user consumption and the benefits it will provide to electricity production as a result. For this, it was shown through graphs that the controller applied with the Artificial Bee Colony (YAK-PI) method for the modernization of the classical controller (PI) unit in the power plant power system reached the targeted value in a shorter time compared to the PI controller applied with the Particle swarm optimization (PSO-PI) method [20].

The stability of the power system was targeted in the study. The controller performances of the two systems providing different systematic operation were compared under different working relations by applying PSO. The optimization process applied on the problem of the balancing design drew attention to the improvement effectiveness on low oscillation and damping. It is also mentioned that the balancing design system is advantageous compared to the individual design [21]. As can be seen from the studies, the PSO optimization algorithm has taken its place in current research.

In this article, the study will be carried out on the PSO optimization method, which provides high accuracy and sensitivity and also provides fast and effective solutions. In order to increase the efficiency of hydroelectric power plants and to produce optimum energy in line with energy production targets, first of all, parameters such as the amount of water belonging to the water basin and flow rate are important in terms of water management. For this, depending on the geographical conditions of that region and seasonal changes, the amount of precipitation and annual averages should be evaluated correctly for water control. The selection of the turbine that converts the potential energy of the water into mechanical energy and the generator that converts the mechanical energy into electrical energy according to the flow rate and water head height of the dam basin is an important factor.

Turbine selection should consider the turbine blade angle and speed values together with the water flow rate and water head height of the plant. The connection between the turbine and generator shafts should be compatible. Among the main turbine types, similar action and reaction turbines such as Pelton, Francis, Kaplan turbines are selected and used depending on the plant conditions. Turbine shaft and wheel blade structures are designed and used in different designs and sizes depending on the plant energy production capacity and environmental conditions.

There are many hydroelectric power plants (*HEPP*) operating with the turbine types in Türkiye. The plants determined as the subject of this study were selected among hydroelectric power plants with high-capacity values and higher economic and environmental impact.

2. Material and Methods

In this study, in order to achieve maximum energy and minimum water consumption from Atatürk, Karakaya, Keban, Altınkaya and Deriner hydroelectric power plants (HEPP), whose names and plant features are given in Table 2, primarily the mathematical modeling process and MATLAB/Simulink as the simulation tool to be used in modeling will be used. The aim of the simulation is to follow the result analyses including various scenarios in order to understand the behavior of the basic components of the hydroelectric power plant from the input to the output. The MATLAB optimization coding (PSO) prepared for the designed MATLAB model diagrams will be applied on the model diagrams. According to the optimization result to be applied for the Atatürk, Karakaya, Keban, Altınkaya and Deriner hydroelectric power plants considered in this study, it is expected to reach the optimum flow rate and the generated power values corresponding to the amount of water consumed according to this flow rate value.

HEPP Modeling Process in MATLAB Simulink

In this process, there are consecutive stages of the formation of the simulation model, which includes the modeling of all components of the HEPP system's mechanical mechanisms (turbine, generator, penstock, etc.), electrical systems (power transmission lines and electronic control devices, etc.) and water (hydraulics).

Step 1: Mathematical Model Functions

When creating mathematical model functions, it is necessary to create a separate model of all elements or components in the process operation. First, two basic target functions related to energy (power) production and water consumption need to be determined.

Max. energy production and min. water consumption will be optimized. MATLAB Optimum water fall height and water flow rate are determined by modeling in Simulink. The mechanical power or energy production of the turbine to be used in the hydroelectric power plant is calculated basically with the following equation.

$$E_t = \eta \cdot \rho \cdot g \cdot Q_t \cdot H_t \tag{1}$$

In this equation, $(\eta)$the turbine efficiency is approximately % 90, (ρ) density of the water fluid (kg/m^3) , *(g)* gravity acceleration (9.81 m/s^2), ($\dot{Q}_t$)volumetric flow rate of flowing water (m^3/s), H_t net düşü yüksekliği (m) the difference between the top surface of the water source in the water basin (energy slope line) water inlet and the turbine water outlet (energy slope line) and (E_t) produced turbine is expressed as the amount of energy (W) . The relevant values for the calculation in the Simulink model are given separately for each power plant in Table 2.

Minimum Water Consumption

In (HEPP) minimum water consumption is determined in Simulink depending on the amount of water entering the turbines from the dam and other hydraulic properties. and can be calculated with the following formula.

$$S_{top} = \sum_{t_1}^{t_2} \dot{Q}_t \cdot \Delta t \tag{2}$$

In this equation ($\dot{Q}_t$)flow rate of fluid water (m³/s), (Δt)time period (hour). Here, minimum water consumption and maximum energy production are tried to be achieved with different scenarios through parameters such as water flow rate, head height and efficiency.

Step 2: Design of MATLAB/ Simulink Model Diagrams

Simulink diagrams designed for system modeling are important in the behavior, simulation and analysis of dynamic systems in MATLAB/ Simulink (HEPP). The model diagrams seen in Figures 5, 6, 7, 8, 9 are designed according to the system flow with all their contents of transfer functions (time) and integral (state) blocks on physical and mathematical basis. The mathematical model parameter input values of the power plants given in Table 2 below and examined in this study are shown in a table. While determining the energy production and water consumption weights in Table 2, the weight values (α) It determines the balance between energy production and (β) water consumption and the efficiency of the system. These are closely related to the plant design, the type of water source and their environmental impacts. It provides information on how to achieve the targets as well as the balance of these weights according to the business policies and optimization targets. The energy production weight (α=0.7) and water consumption weight (β=0.3) were determined according to the characteristics of each plant and environmental impacts. These selected values provide optimum conditions as well as efficient and sustainable operating conditions from the plants. As a result, the basic criteria for weight selection are:

Environmental Factors: Evaluating water consumption at minimum scales in cases where water resources are limited.
Energy Demand: In situations where energy demand is high, it is preferable to give priority to energy production.
Hydroelectric Power Plant Characteristics: In large power plants, energy production is generally the priority.
Efficiency and sustainability: It should be emphasized that the necessary legal regulations are important to optimize social and economic impacts. The selection is made by taking such factors into account.

As a result, the values expressed in Table 2 were entered into the model diagrams and the flow diagrams in Figures 5, 6, 7, 8 and 9 were obtained. Then, the MATLAB-PSO optimization code expressed in Figure 10 below was applied to the model and the optimum flow rate and the water consumption and energy production values obtained as a result of this optimum flow rate were reached as seen in the indicators of the figures below.

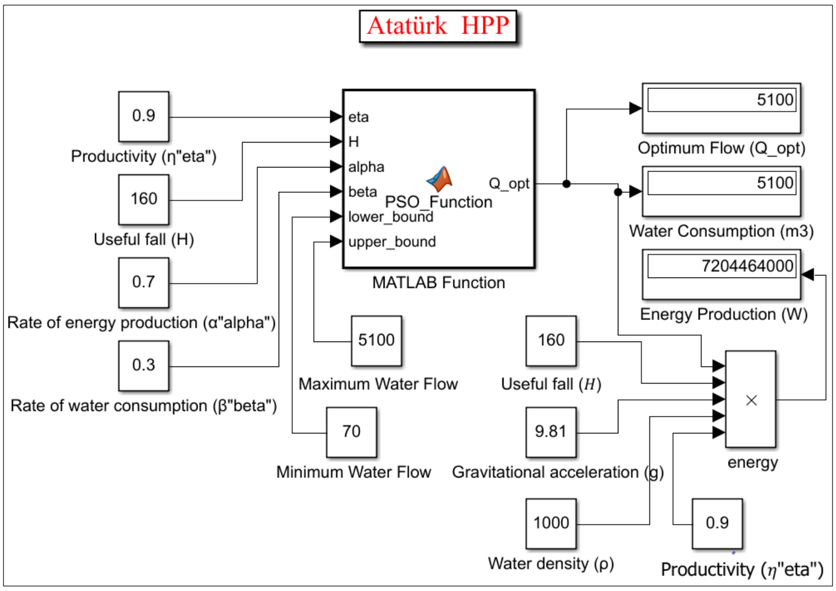

Figure 5. Atatürk HEPP Model Diagram

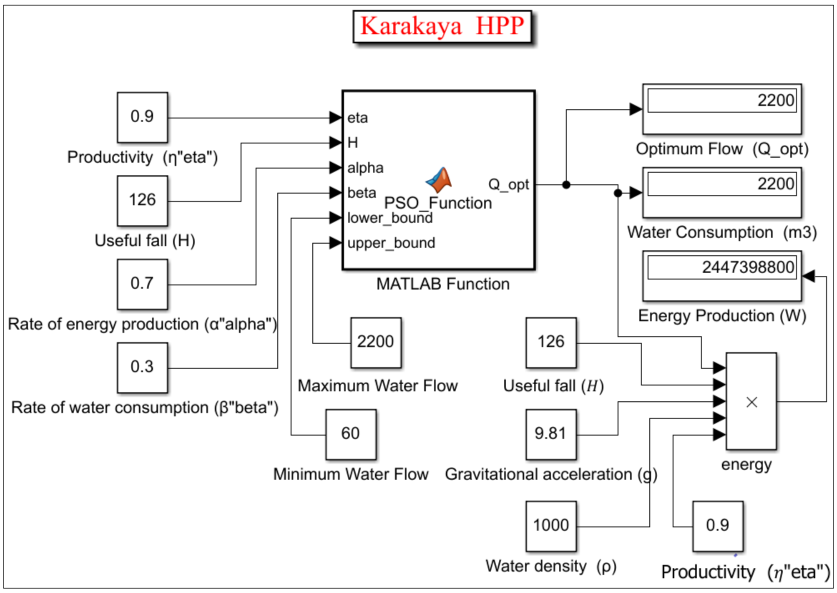

Figure 6. Karakaya HEPP Model Diagram

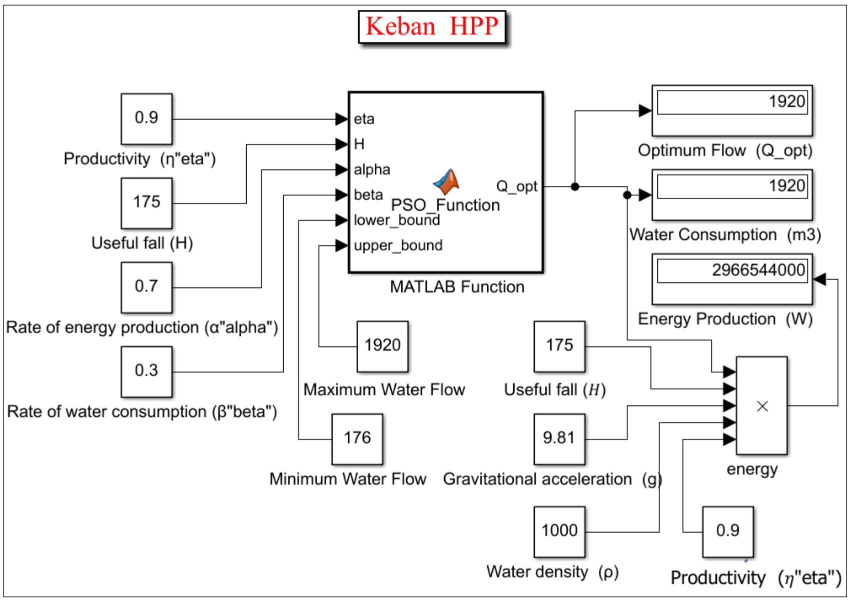

Figure 7. Keban HEPP Mathematical Model Diagram

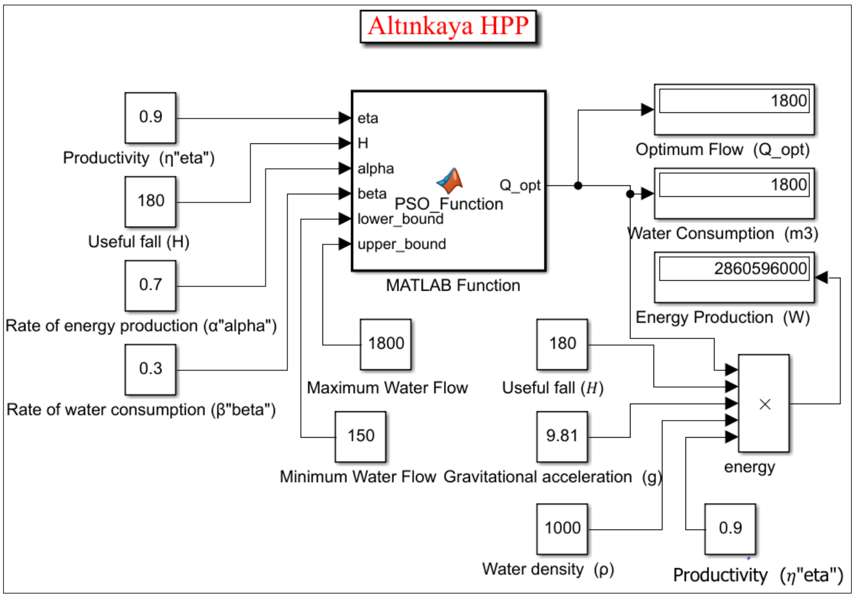

Figure 8. Altınkaya HEPP Model Diagram

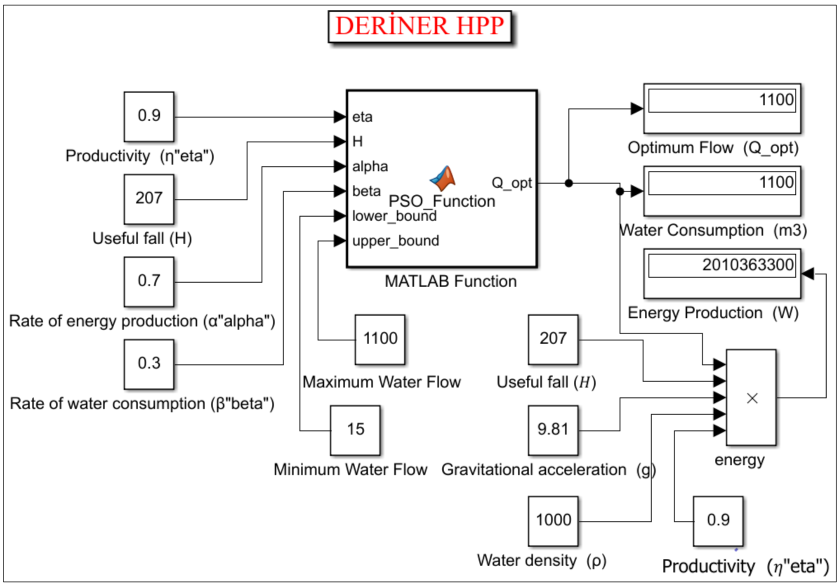

Figure 9. Deriner HEPP Model Diagram

Step 3: Implementation of PSO Algorithm

First of all, if we give information about PSO optimization, Particle Swarm Optimization (PSO) is an effective method for optimizing energy production in hydroelectric power plants. PSO is a heuristic algorithm inspired by nature and works with a swarm intelligence approach. It is particularly successful in solving high-dimensional, complex and non-linear problems. The balance between energy production and water consumption is tried to be achieved with the PSO optimization method [14].

Importance of PSO in Hydroelectric Power Plants (HEPP)

- It ensures that the turbine installed in the HEPP operates under optimum conditions. The turbines can operate with maximum efficiency at different water flow rates and dam water levels. The PSO algorithm analyzes the complex relationship between these parameters and determines the optimum operating conditions.
- In energy production planning, PSO can make production planning by considering factors such as demand forecasting and water resources management. In this way, production strategies suitable for demand changes are developed.
- Optimization of turbine operating points to minimize hydraulic and energy losses in terms of loss and cost reduction is possible with PSO. It also provides cost advantage.
- adaptive optimization in such variable systems.
- PSO stands out with its ability to perform multi-purpose optimization when multiple targets such as energy production, water storage and flood control need to be optimized. It also provides advantages due to reasons such as fast and effective solution and easy applicability.

The formula of the PSO algorithm shown in equations 3 and 4 below is preferred due to reaching a fast result or solution with one or more selected parameters. It updates the position and speed between the past and the current best. Considering the PSO algorithm, the speed and position of any particle are expressed in the following equations, respectively;

$$v_{i(t+1)}^{new} = w + v_{t+1}^{old} + c_1 r_1 (P_{best} - x_{t+1}) + c_2 r_2 \ (G_{best} - x_{t+1}) \quad (3)$$

$$x_{i(t+1)} = x_{i(t)} + v_{i(t+1)} \quad (4)$$

In the equations, (x_t)specified particle position, $(v_t)$is the rate of change of the particle, (c_1 , c_2) the size of the number of steps to reach the solution or the learning coefficients ($0 \leq c_1, c_2 \geq 2$), (r_1, r_2) the new values randomly generated at each speed change ($0 \leq r_1, r_2 \leq 2$), (w)acceleration coefficient ($0.5 \leq w \leq 1$) and determines the behavior of the particle depending on the speed, (P_{best}) particle particle closest to the solution position, (G_{best}) indicates the closest position to the solution among all particles in the global. The speed and position of the target criterion are determined according to the maximum iteration number.

Below is the MATLAB coding. Mathematical models will be optimized with these codes.

```
function Q_opt = PSO_Function (eta, H, alpha, beta, lower_bound, upper_bound)
  % PSO Parameters
  num_particles = 20; % Particles number of
  num_iterations = 50; % Iteration number of


  % Beginning positions And speeds
positions = lower_bound + (upper_bound - lower_bound) * rand (num_particles, 1);
velocities = zeros (num_particles, 1);

  % Personal and global en Good values
  personal_best_positions = positions;
  personal_best_scores = inf (num_particles, 1);
  global_best_position = 0;
  global_best_score = inf;

  % PSO Döngüsü
  for iter = 1:num_iterations
    for i = 1:num_particles
      Q = positions(i); % Debi değeri

      % Energy production And This consumption calculation
      energy_production = eta * H * Q;
% Energy production calculation (P = η * H * Q)
      water_consumption = Q; % This consumption flow rate equal

% Fitness function : Energy maximize , water Minimize your consumption
fitness = -α* energy_production + β * water_consumption ;

      % Personal -most Good value update
      if fitness < personal_best_scores ( i )
        personal_best_scores(i) = fitness;
        personal_best_positions(i) = Q;
      end

      % Global en iyi değeri güncelle
      if fitness < global_best_score
        global_best_score = fitness;
        global_best_position = Q;
      end
    end

    % Speed And position update
    for i = 1:num_particles
c1 = 1.5; % Personal pull coefficient
c2 = 1.5; % Global attraction coefficient
      inertia_weight = 0.7; % Eylemsizlik katsayısı

      velocities(i) = inertia_weight * velocities(i) ...
+ c1 * rand () * (personal_best_positions(i) -positions(i)) ...
+ c2 * rand () * (global_best_position - positions(i));

      positions(i) = positions(i) + velocities(i);

      % Pozisyon sınırlarını koruma
      positions(i) = max(positions(i), lower_bound);
      positions(i) = min(positions(i), upper_bound);
    end
  end
  % Optimum flow rate value
  Q_opt = global_best_position ;
end
```

Figure 10. To the power plants Applied MATLAB PSO Code

Determination of Target Function:

In the PSO (Particle Swarm Optimization) method, the target function (*Fitness*) for the most suitable flow rate expressed in the equation 5 below is a mathematical model of the problem to be solved and represents a value that measures the quality of the solution. In other words, it determines how good or bad each solution candidate (particle) is during the optimization process. The objective function usually refers to a value that needs to be maximized (*production*) or minimized (*consumption*). For example, when considering a function minimization problem, the objective function is to find the lowest value. Similarly, when considering a function maximization problem, the objective function is to determine the highest value.

In PSO, each particle represents a candidate solution in the solution space and the value of this solution in the target function determines the particle's fitness or compatibility level. Particles move in a swarm to find the solution with the lowest (or highest) target function value. In this study, it is aimed for the energy production to be at maximum and the fluid flow rate to be at minimum. The efficiency-based optimization is intended to be carried out with the fitness function in equation 5 calculated in PSO, which is a formula that balances two opposing goals.

Calculation of the Objective Function in Coding:

While calculating the most suitable flow rate value within the coding, the target function of the PSO algorithm is designed as follows:

$$\text{Fitness} = -\alpha.\,\text{Energy Production} + \beta.\,\text{Water Consumption} \quad (5)$$

Equation 5, the energy production value is determined by the equation given below.

- $\text{Energy Production(P)} = E_t = \eta.H.\dot{Q}$ (6)

In this equation, (η) is expressed as efficiency (0.9), (*H)* is useful height, ($\dot{Q}$) is the flow rate of consumed fluid (water) (m³/s). ($\dot{Q}$) flow value also represents the water consumption value in the formula.

- Fixed Parameters and Formula

It expresses the plant characteristic values such as efficiency, useful height, energy and water consumption weight value etc. obtained from Table 2 to be used in modeling.

For Atatürk HEPP:

Among the dams examined here, only the Atatürk Dam has fixed parameters and target function value. calculated according to the following values.

From Table 2, the useful height for Atatürk HEPP is H = 160 m, efficiency η = 0.9, energy weight α = 0.7, water consumption weight β= 0.3. Efficiency (η) and weights (α, β) are unitless. The calculation parts in the coding in Figure 10 are given below.

- Energy production = eta * *H* * *Q*
- Water consumption = *Q*
- Fitness function

*fitness = - 0.7 * energy production + 0.3 * water consumption;*

max. and min. range the calculation for the randomly selected sample flow rate $Q = 150\ m^3/s$ is given below.

- ***Energy Production:***

$P = 0.9 \times 160 \times 150 = \mathbf{21600}$ MW (Megawatt)

- Water Consumption (flow rate): $Q = 150\ m^3/s$
- ***Fitness function:***

Fitness = $-\ 0.7 \times 21600 + 0.3 \times 150 = -15120 + 60 = \mathbf{-15075}$

As can be understood from the example, the calculated fitness values and the max. and min. water flow rates are shown in the diagram given in Figure 5. This coding, which works within the MATLAB function calculation as function input, works for 100 seconds according to the results obtained from the PSO algorithm according to different iteration (50) and particle (20) number values until the most suitable value is calculated with the fitness function. As a result of the values calculated in the PSO algorithm and MATLAB functions, the optimum flow rate and energy production depending on this flow rate value are provided. The PSO algorithm method, exemplified by the Atatürk Dam, has been applied to other HEPPs and the relevant diagrams are given.
The coding in Figure 10 above, expressed in the study, tries to maximize the energy production of the particles while minimizing the water consumption. As a result of the application, both in Figure 10 and in Figures 5, 6 7, 8 and 9 The mathematical models shown above were applied for optimization and optimum flow rates were obtained in both.

3. Results and Discussion

The best solution obtained (G_{best}) and (P_{best}) Optimized values are presented in terms of energy production and water consumption. These optimum values indicate that the maximum energy value to be obtained from the plant is obtained with minimum water consumption. Accordingly, the optimum result values are shown in Table 3 below.

These optimum values are given in Figures 5, 6, 7, 8 and 9. While it is shown on mathematical models, it is also shown in the graphs given in Figures 11-12-13-14-15 below.

Table 3. Power Plant Values Obtained as a Result of Optimization

Optimum Values	Hydroelectric Power plants (*HEPP*)				
	Atatürk	**Karakaya**	**Keban**	**Altınkaya**	**Deriner**
This Flow rate (m^3/s)	5100	2200	1920	1800	1100
Energy Production (MWh)	7204	2447	2966	2860	2010

In figure 10 on mathematical modeling in MATLAB / Simulink, the flow, energy and target function curves are shown graphically in Figures 11-12-13-14-15 below.
As can be seen from the figures, the target function curves of the most suitable fitness values are shown graphically in equation 5 in order to achieve the maximum energy production and minimum flow consumption targets intended within the PSO algorithm.

In PSO, each particle represents a candidate solution in the solution space, and the value of this solution in the target function determines the particle's fitness or fitness level. Particles move in a swarm to find the solution with the lowest (or high) target function value. In the PSO algorithm, it continues to work until a certain stopping criterion (e.g., maximum number of iterations or desired target function value) is reached, and this target function values are updated in each iteration and the best solution (*fitness value)* is obtained.

Simulink model diagrams allow maximizing energy production-oriented production. If the energy weight is taken as α = 0.5 and the water consumption weight is β taken as 0.3, then energy production and water consumption can be expressed as balanced energy production.

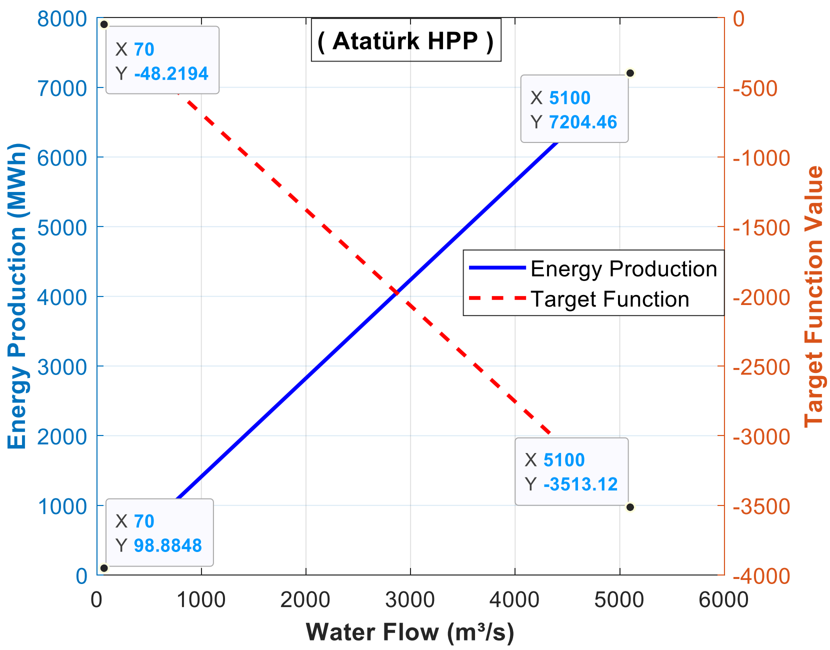

Figure 11. Atatürk HPP Max. Energy- Min. Flow Graph

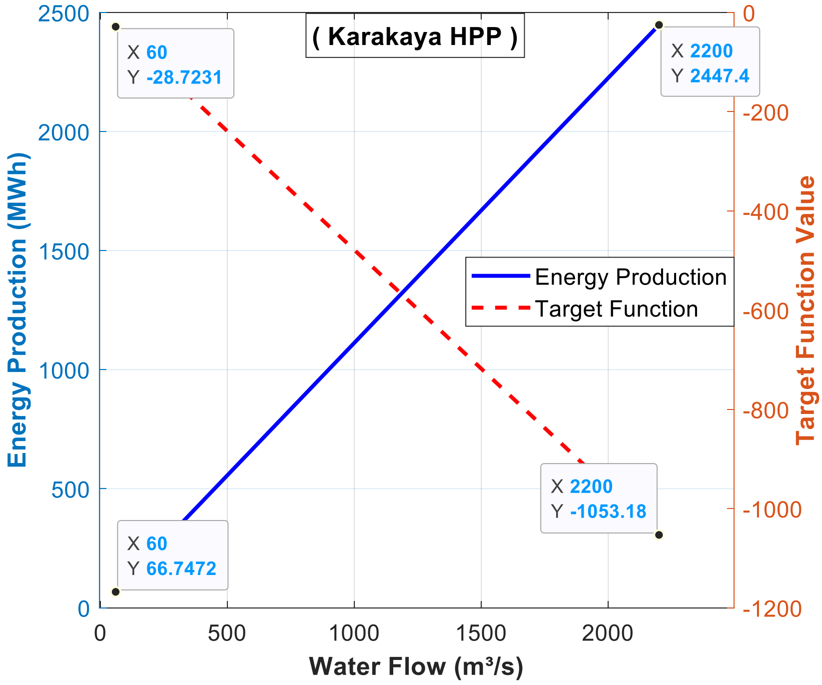

Figure 12. Karakaya HPP Max. Energy- Min. Flow Graph

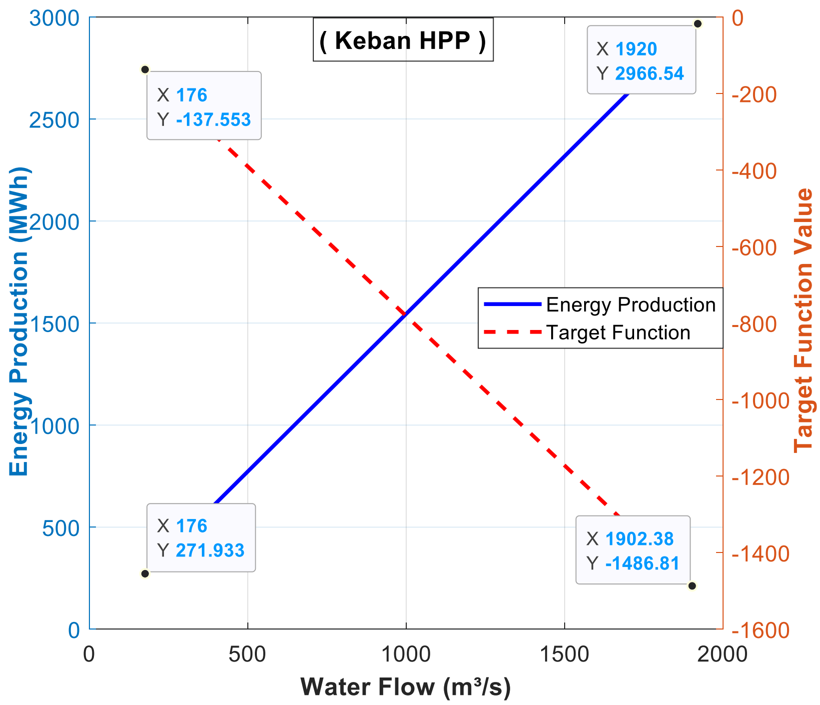

Figure 13. Keban HPP Max. Energy- Min. Flow Graph

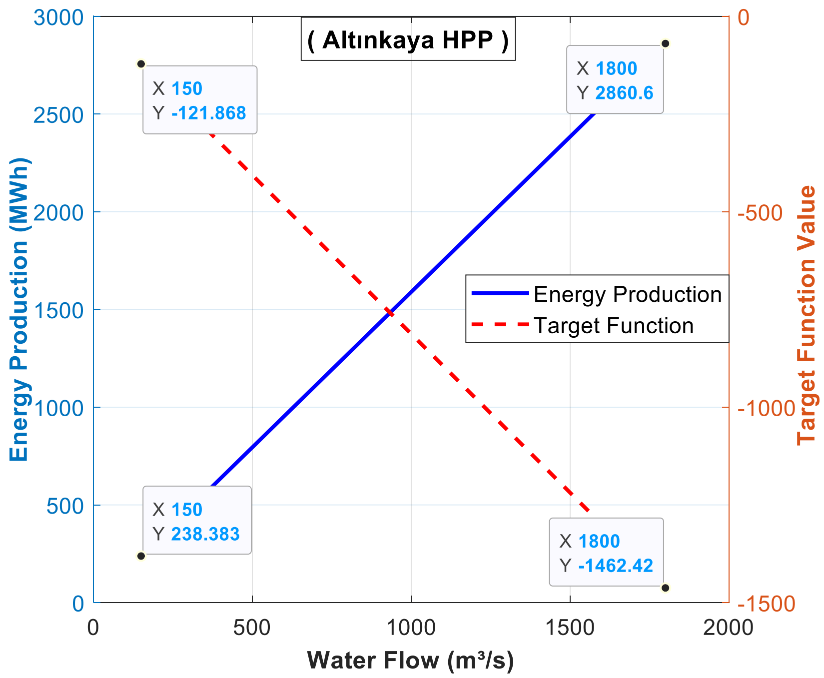

Figure 14. Altınkaya HPP Max. Energy- Min. Flow Graph

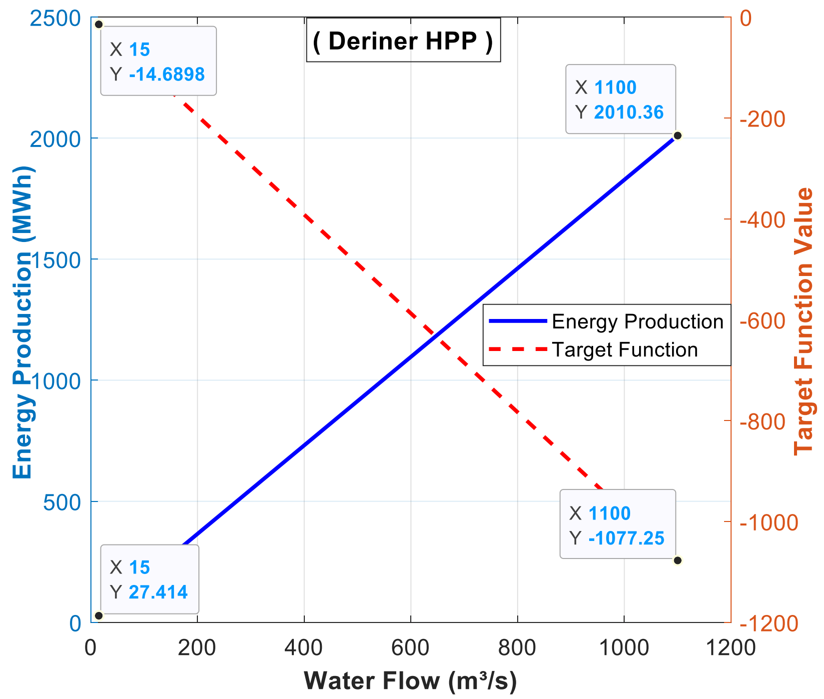

Figure 15. Deriner HPP Max. Energy- Min. Flow Graph

4. Conclusion

In the graphs obtained with the values calculated according to the specified algorithm in Figure 10 for each HEPP, the energy production value and the target function value change according to the flowing fluid flow. It is seen from the graphs that the energy production value increases as the water flow rate increases, while the target function value gradually decreases.
In the graphs, for example, flow and energy production according to X and Y coordinates and flow and target function values (fitness) can be followed point by point. It can be observed that these values correspond to different values for each HEPP depending on the flow rate of the fluid flowing from the dam. Likewise, since the water head heights are also different, the energy production and target function values corresponding to the same X and Y value will naturally be different. As a result, the aim is to determine how to determine the maximum energy production and minimum water consumption and the maximum electricity production with the minimum water use separately according to the PSO algorithm.
The correct use of water resources is thus ensured to be controllable. As a result, there should be a balance in the energy production of existing or new HEPPs to be established. This is important, because changes can be observed according to environmental and climate conditions. The important thing is to maintain the balance and ensure sustainability. Providing maximum energy and minimum water consumption in hydroelectric power plants offers great advantages if adjusted correctly. The applied optimization should be constantly monitored and, if necessary, adjusted considering environmental factors and the water ecosystem.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

Conflicts of Interest:

The author declares no conflict of interest.

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