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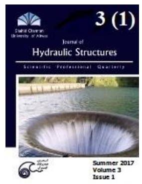

The Optimization of Energy Supply Systems by Sequential Streamflow Routing Method and Invasive Weed Optimization Algorithm; Case Study: Karun II Hydroelectric Power Plant

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Abstract

Among the major sources of energy supply systems, hydroelectric power plants are more common. Energy supply during peak hours and less environmental issues are some of the most important advantages of hydroelectric power plants. In this study, designing parameters to supply maximum amount of energy was determined by using the simulation-optimization perspective and combination of IWO-WEAP models. Subsequently, the developed model has been applied for designing the Karun II hydroelectric power plant. The sequential streamflow routing method has been developed for obtaining energy in WEAP water resources management software. In addition the optimization algorithm has been applied to optimize the invasive weeds. To verify the performance of this method, obtained results for the firm energy were compared to those of the total energy. Using this method, for 1398 GWY (Giga watt per your) firm energy, the minimum and normal levels of operation were 668 and 672 m.a.s.l (meters above sea level), respectively, and the installation capacity calculated around 498 MW as optimal value.

Keywords: Sequential streamflow Routing method, Invasive weed optimization algorithm, WEAP model.

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1. Introduction

Hydropower energy is one of the renewable energies with lots of merits compared to other

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types of fossil fuel energies such advantage as clean, renewable, low-cost, and flexible. The optimization of hydropower systems has got great significance to the stable, safe, and economic operation of the whole power system. The optimization methodologies can be categorized into two: one is based on mathematical programming which mainly including linear programming (LP) (Ouyang et al., 2014), non-linear programming (NLP) (Mohan, 1997), dynamic programming (DP) (Geem, 2006), decomposition and coordination of large scale system network-flow methods (LSSDC) (Chu and Chang, 2009), and the progressive optimality algorithm (POA) (Luo and Xie, 2010). The second type of reservoir optimization system is based on heuristic algorithms such as the genetic algorithm (GA) (Geem, 2011), simulated algorithm (SA) (Barati, 2011), evolutionary algorithms (EA) (Xu et al., 2012), particle swarm optimization (PSO) [10], and ant colony algorithm (ACO) (Karahan et al., 2013).

IWO algorithm (Mehrabian and Lucas, 2006) is a new bionic intelligent algorithm which simulates the spatial weed diffusion, growth, reproduction, and competitive survival of the invasive weeds (Peng et al., 2015). IWO algorithm has been widely used in a variety of optimization problems and practical engineering problems. Such multi-objective optimization problems as stated by Kundu et al., 2011 are parameter estimation of chaotic systems (Ahmadi and Mojallali, 2012), model order reduction problem (Abu-Al-Nadi et al., 2013), global numerical optimization (Basak et al., 2013), antenna arrays problem (Zaharis et al., 2013; Zaharis et al., 2014), unit commitment problem (Saravanan et al., 2014), optimal power flow problem (Ghasemi et al., 2014), flow shop scheduling problem (Zhou et al., 2014), traveling salesman problem (Zhou et al., 2015), and economic dispatch (Barisal and Prusty, 2015). Evenson and Moseley used an optimization model to minimize the total costs of a multi-reservoir system along with the simulation models (Evenson and Moseley, 1970). Diaz et al. used an optimization model to maximize the economic benefits from the sale of energy in the multi-reservoir hydroelectric system (Diaz, et al., 1989). Wardlaw et al. used a genetic algorithm for optimal exploitation of the reservoir (Wardlaw, et al., 1999). Tsoukalas et al. dealt with optimizing the operation of the multi-reservoir systems by integrating the WEAP simulation model with heuristic techniques (Tsoukalas, et al., 2013). In Karun river, several studies have been done regarding hydropower energy and some factors affected in power plant generation systems such as sedimentation. The best estimation of the Karun river suspended sediment load was produced by Bagnold method as less erroneous predictions was obtained (Najafpour et al., 2016).

Hydropower plants optimization is able to produce considerable economic benefits without any additional cost. Based on theoretical research and practice, the optimization of hydropower scheduling can increase power generation by 1% to 7%. The hydropower reliability also has to be simultaneously evaluated, as it is based on a natural inflow with some uncertainties. As an indicator for the reliability of power generation, firm power can be used. Theoretically, it is the output of mean power in a distinguish critical period. The critical periods are distinct for different types of hydropower plants, for example, run-of-river or daily regulated plants take a day as the critical period, and annually regulated plants take the dry season as the critical period. For most studies, the firm power calculation is handled by the duration frequency curve of the outputs, of which the one with the design guarantee rate of the hydropower station is chosen as the firm power. Hence, the calculated firm power differs from the defined one. For example, suppose the outputs in a certain critical period are 70, 30 and 200 MW, respectively, and thus the mean output is 100 MW, which is defined as the firm power. Normal operation is inferred for this hydropower plant according to the definition. However, in reality, the normal operation is broken twice as the output has been below 100 MW twice. To avoid such a contradiction, a penalty function is frequently used to guide the power output process towards the firm output. Nevertheless, the use of penalty functions equalizes the generation process and affects the optimization of the whole power generation.

In this paper, the sequential streamflow routing method and its combination with the optimization algorithm of invasive weeds for the energy simulation was used. The least operation level, the normal head and the installation capacity of the hydroelectric power plant for the Karun II hydroelectric power plant, were optimized for the highest secure energy and the total energy in order to build a dam capable of providing the maximum value of hydroelectric energy at peak hours and secondary power during other hours of the day. Furthermore, we have applied the hybrid invasive weed optimization (HIWO) algorithm to the parameter estimation of nonlinear hydropower generation.

2. Materials and Methods

In the following, the simulation model of energy and WEAP model as simulator and the invasive weeds algorithm as the proposed optimization method and the optimization of parameters for designing Karun II was discussed.

2.1. WEAP simulation model and its application in modeling energy generation

2.1.1. Simulation of water resources in WEAP

WEAP model is an appropriate computer tool for integrated water resources planning, which has been developed by the Stockholm Environment Institute offering a wide range of applications in the world and the country, in recent years. The advantage of WEAP in the integrated approach is in simulating water resource systems and applying operation policies. WEAP performs based on balance sheet equation and can be used in complex modeling in water resource managements (Sieber, et al., 2012).

The first step in simulating in WEAP is entering the information and assumptions required to express operation policies, costs and such factors as hydrology and pollution parameters, needs and supplies. After creating various operation scenarios in this program, the effect of different assumptions or policies on the availability and consumption of water can be evaluated.

2.1.2. Energy simulation in WEAP

Despite its great abilities, WEAP has some weaknesses in simulating hydropower systems. The WEAP model Not only has weakness in calculating hydroelectric energy but also cannot be able to computing the conditions at the end of the time steps and other important parameters in modeling of hydroelectric power plants.

In this regard, a hydroelectric computing module based on sequential streamflow routing method includes two important components of allocation based on hydroelectric objectives as well as simulating energy generation using the scripting feature within the developed WEAP environment (Razi Khosroshahi, et al., 2015). The scripting feature provides control over data and input parameters, access to the results and allows reimplementation of the model in addition to the provision of programming. WEAP model provides the ability to use VBScript programming. With regard to the specification of this ability for WEAP in the advanced section of the software, it eliminates such problems as exporting data from WEAP to external environments and importing data from other applications.

2.1.3. Allocating water with the aim of producing energy

Firm capacity is the amount of energy available for production or transmission which can be (and in many cases must be) guaranteed to be available at a given time. Firm energy refers to the actual energy guaranteed to be available. Non-firm energy refers to all available energy above and beyond firm energy.

Firm energy is often available at substantial discounts over non-firm energy sold on the spot market. Energy producers such as hydroelectric plants and wind farms may have non-firm energy available due to unexpected weather or seasonal conditions (U.S. Army Corps of Engineer, 1984).

The important thing at this stage is that in order to allocate water to produce energy, as well as environmental objectives, drinking, industry and agriculture, which is essentially non-consumable, should be determined and defined through tools available in the model and dividing the hydroelectric power plants. The water need of energy generation in each time step, which is in the form of water release volume that passes through the water tunnel to the power plant, depends on the net head of the power plant at that time step. About the storage power plants, the tail-water level not only varies by time and discharge, but should also be considered as the average level of the beginning and end of the time step.

To define the water requirements of energy generation, Expressions and Scripting capabilities within WEAP software are used. It is worth noting that in fact, WEAP software conducts a systematic simulation, and at the beginning of each time step, it only provides access to the values of variables at the beginning of that time step. Therefore, it is not possible to normally define the exact water requirement for energy generation for each of the power plants using the conventional method, because the calculation of net head at each time step requires the data of storage level at the beginning and end of the time step, while the software provides access to water storage levels at the end of the time step and cannot provide data for time steps before the simulation time. In this regard, provided a trial and error trend for water allocation based on energy generation purposes in a way that water requirement of energy generation is performed in an accurate way and considering the storage at the beginning and end of each time step. After water allocation, simulation of energy generation was done. The three main factors of net head, flow discharge from the power plant and continuity of long generation hours affect energy generation. The second and third factors can be gathered in form of the factor for the volume of water passing through the plant; but as there are determining thresholds for time and discharge, the volume of water will be taken into account as two separate factors of time and discharge in the simulation calculations of energy generation. Hence, in this study, the objective function used in the optimization algorithm attempts to find the highest firm energy and maximum total energy by try and error trend to provide new design parameters.

2.2. Karun II Hydroelectric Power Plant

Karun II Hydroelectric Power Plant will be built on the hillsides of Zagros Mountains and in a range between Karun III and I dams at the geographical location of Eastern longitude of 49° 58' 08" and the Northern Latitude of 31° 58’ 06"at 95 km upstream of Karun I dam and 25 km downstream of Karun III dam. (Dezab Consulting Engineers, 2014) The annual average flow at the place of the dam is about 8.367 billion cubic meters on Karun II including the dam on Karun III and the maximum ten-thousand-year flood entry to Karun II is more than 10510 cubic meters per second by calculating the distribution of the flood in Karun III reservoir. Karun II is studied for the main purpose of providing peak energy and secondary objectives of flood control and regulating the outflow of Karun III (Figure 1)

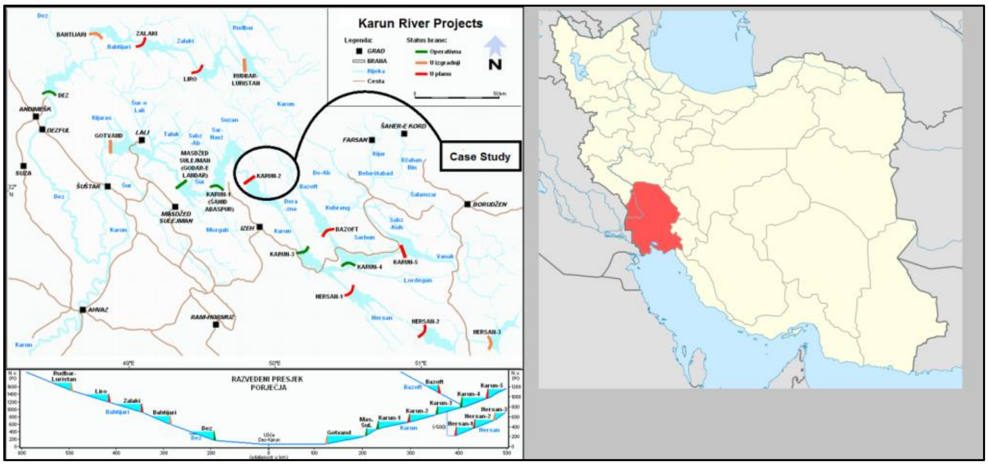

Figure 1. Location of Karun II in among all projects of Karun River

2.3. Invasive weeds optimization algorithm

The weed optimization method has been introduced through inspiration by nature. This algorithm is very effective and fast in finding optimal locations in addition to being simple, and acts based on the basic and natural features of weeds such as seed generation, growth and struggle for survival in a colony. The procedure of this algorithm can briefly be stated as follows: (Figure 2)

Invasive weeds optimization model leads to optimization through reversing the unpleasant incident of weed growth on farms. Invasive weeds have two unique features of optimality and resistance. They act according to the popular theory of r/k selection over time (Mehrabian, et al., 2006).

2.3.1. Theory of r/k selection

This theory states the behavior of weeds in survival stages. The parameter of r refers to rate and describes the uncontrolled, low quality and short-life proliferation rate of the plants in the environment at the beginning of dispersion. In addition, k from the word Kapazitat refers to the low rate of regeneration and enhanced quality of life and lifetime of the plants over time.

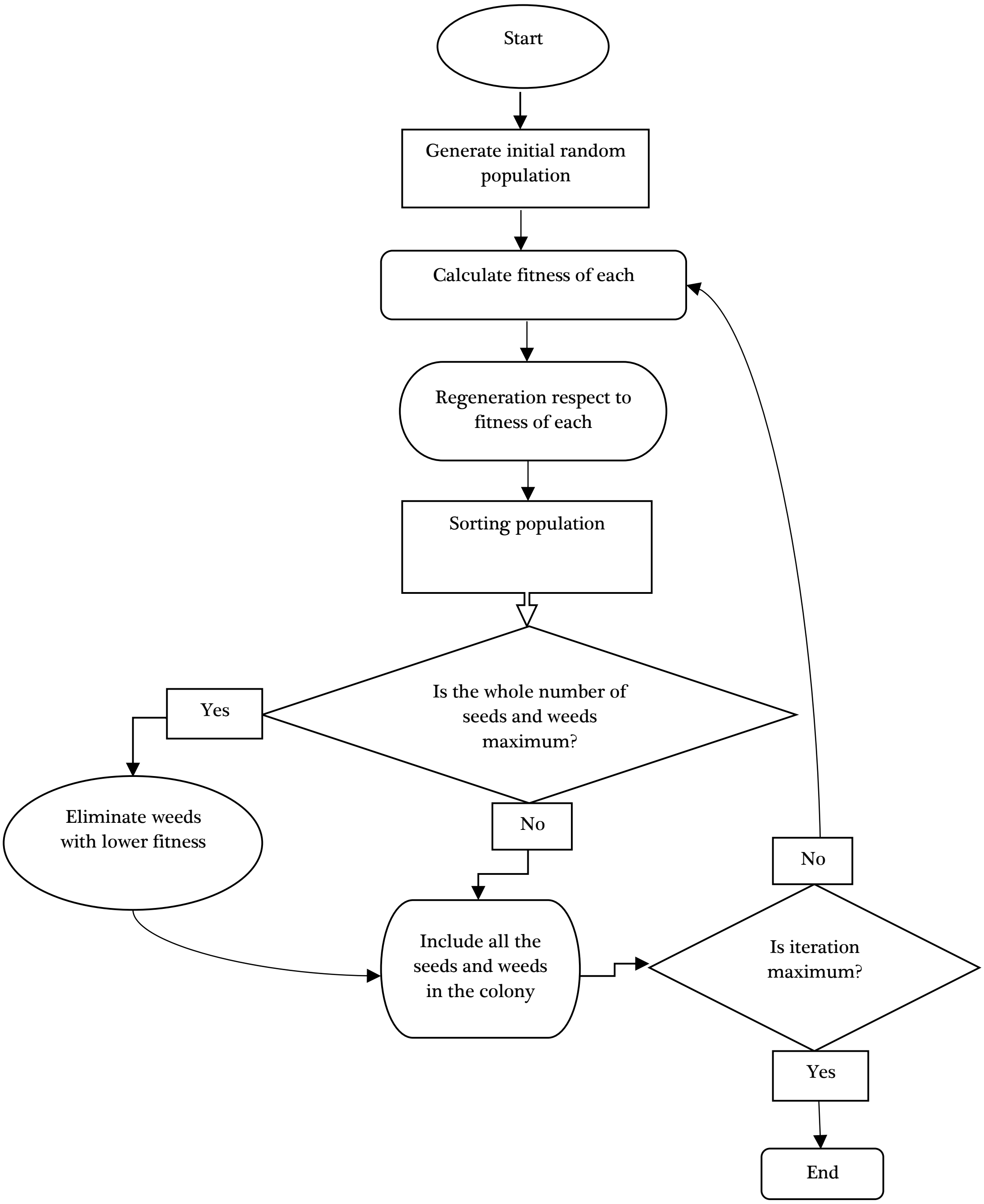

Figure 2. Invasive Weed Optimization Algorithm

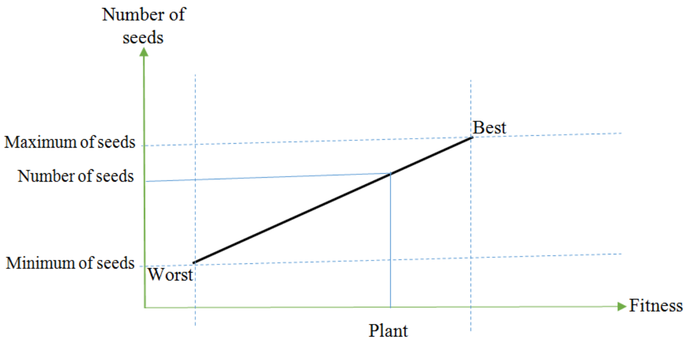

Figure 3. the relation of fitness with number of seeds

2.3.2. Life stages of invasive weeds

The just purpose of a weed is survival and in order to achieve this goal, it seeks for the best livable environment. At first, the initial population is randomly dispersed throughout the space. The seeds grow and due to their fitness can produce zero to five seeds in the range of their capacity. Figure 3 shows the relation between fitness and number of seeds.

In case the problem is minimalist, the number of children follows the equation 1.

$$S = \left[S_{min} + (S_{max} - S_{min}) * \frac{F - F_{worst}}{F_{best} - F_{worst}}\right] \quad (1)$$

Seeds around the mother plant are distributed using a normal distribution with an average of zero and in the range of standard deviation that is obtained from equation 2.

$$\sigma_t = \left(\frac{T-t}{T}\right)^n * (\sigma_{initial} - \sigma_{final}) + \sigma_{initial} \quad (2)$$

In equation 2, n is the speed control of the reduced dispersion, which reduces speed if it is between 0 and 1 and increases dispersion speed if it is more than one (Figure 4). Here, for the first and final standard deviation (σ) it were used a values of 1 and 0.001 respectively.

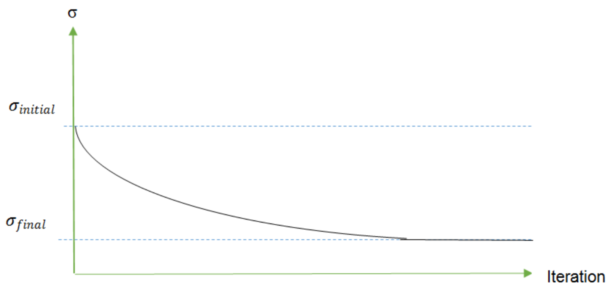

Figure 4. Regeneration respect to fitness of each standard deviation (σ)

During time cycle, the number of plants in the colony have been considered as fixed and plants that have the least fitness in comparison to the rest of the colony will be eliminated to reduce calculations and limit the environment.

In order to end this trend in optimization problems, the ending conditions are imposed and the location of the most optimal plant is selected as the answer to the optimization problem. In this study, 40 iterations have been closed to the answer however to increase reliability of results, the iterations continue up to 100 times.

2.4. The IWO - WEAP simulation - optimization model

To start the optimization module, first, for the primary plants have been produced random values. Then the WEAP model and the simulation module start under the command of the optimization module, and the simulation module is implemented only once for each particle. After that, hydro energy characteristics are calculated. At every step of the optimization algorithm, the best plant is selected as the most optimal response to the target function from among the produced plants. After running the algorithm to a certain number of iterations, the stop conditions of the algorithm will be controlled.

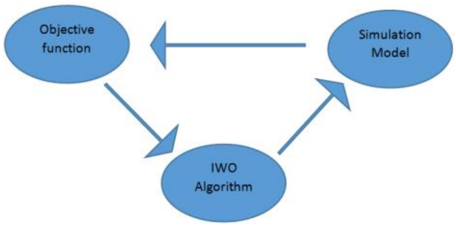

Figure 5. The circle of the simulation Hierarchy- Optimization

3. Results and discussion

In this section, the developed IWO-WEAP simulation-optimization model is utilized in the optimized design of Karun II power plant elements and then, the results are presented. Two different decision variables were used in this study which are normal water level (NWL) and minimum water level (MWL). Beside it, these variables were applied in two scenarios. The range of these levels in two different operation scenarios have been presented in Table 1. Due to determine of the storage of Karun II dam assumed that the Karun III dam's (it is the upstream of Karun II) outflow during peak hours (6 hours) is equal 30 million cubic meter per second. The parameters used in the IWO algorithm in this study are shown in Table 2.

Table1. The scope of decision variables

Decision variable	Minimum	Maximum
Normal level of operation (masl)	664	672
minimum operating level (masl)	640	668
Installed capacity(MW)	200	800

Table 2. Parameters used in the IWO algorithm

Parameter	value
Coefficient of dispersion	2
Minimum standard deviation	0.001
Maximum standard deviation	1
Minimum of seeds	0
Maximum of seeds	5
The initial population size	10
The maximum population size	20

In order to end, the program was run once for the total energy and once for the firm energy and the results obtained as follows. In both cases, the normal level and the minimum operation level were obtained as 672 and 668 meters above sea level, respectively. It can be observed that when the model is run for maximalist of the firm energy, the firm energy and total energy are 1393.14 and 2019.86 MWY (Mega Watt per Year), respectively, and the installation capacity equals 498 MW. However, in maximalist mode of the total energy, the values obtained for the firm energy and total energy are 1403.19 and 2022.80 MWY (Mega Watt per Year), respectively, and the installation capacity equals 503 MW. This indicates that perhaps through maximizing the total energy, the firm energy has increased in comparison to the mode in which was run the model for maximizing the firm energy. However, the installation capacity has also increased. If the installation capacity was increased more than 498 MW when running the program in the firm energy mode, the amount of energy will be reduced, which indicates the proper function of the model. The results of using the developed model (IWO-WEAP) of the Karun II hydroelectric power plant are shown in Table 3.

Table 3. The results of the IWO-WEAP model

Firm energy		Total energy	
Installed capacity (MW)	498	Installed capacity(MW)	503
Normal water level (masl)	672	Normal water level (masl)	672
minimum water level (masl)	668	minimum water level (masl)	668
The total annual energy (GWY)	2019.86	The total annual energy (GWY)	2022.80
The firm annual energy (GWY)	1393.14	The firm annual energy (GWY)	1403.19

4. Conclusion

In this research, the simulated hydro-energy of sequential flow routing, which has been previously upgraded for the WEAP software, has been developed by the optimization algorithm of invasive weeds of the structure of an optimization simulation model to obtain the best mode of dam design features in case of the increase in total energy or firm energy. As cleared, the maximum (normal) and minimum operational water levels are at optimum state and by increasing the value of the maximum (normal) and minimum operational water levels the values of the objective functions may improve, but due to the technical factors and the type and the working condition of Karun II power plant (including the flow of the power plant, the effects of Karun III, etc.) the normal values and the least operation cannot be increased over a specific value. In the case of total energy maximization, it is observed that the firm energy has obtained higher value.

Based on this study, it can be seen that the best possible condition regarding energy generation with the maximum (normal) and minimum operational water levels with designs conducted in reports of the dam by the consulting engineers of the project is a much lower obtained installation capacity than the amount of energy generation reduced in this mode. The abovementioned calculation is an evidence that increase in installation capacity cannot be a guarantee for maximization of benefits.

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