POSSIBILITIES OF INCREASING THE ENERGY PERFORMANCE OF HYDROELECTRIC PLANTS FROM BIHOR COUNTY BY INTEGRATING THE FLOATING PHOTOVOLTAIC PANELS

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ABSTRACT: The paper addresses the issue of floating photovoltaic panels on the reservoirs of hydroelectric power plant dams to increase energy performance and yield. In addition to lakes, photovoltaic panels can also be mounted on the runoff channels of hydropower plants, both on water and on the edges landscaped with concrete structures. In these cases, the panels are fixed. Some reservoirs also have the possibility of setting up on the dammed side, which is mostly made of compacted earth. Three hydropower plants from the Bihor County development were studied. Two located in the plain area with reservoirs, one with runoff channels near the city of Oradea, the county capital, and a dam with lateral approaches located in a mountainous area. The characteristics of the existing electrical energy evacuation facilities and components that must be additionally installed for the conversion of the energy into direct current given by the photovoltaic panels into alternating voltage for injection into the regional electrical energy system are described. For each location, the characteristics of solar radiation and the available surfaces of reservoir lakes for the installation of panels are evaluated. The components of a floating system are also presented in the paper. After the study carried out and the presentation of the research results at the end, the conclusions and observations of the authors regarding the theme of the paper are presented.

KEYWORDS: Hydroelectric plants, photovoltaic panels, floating installations

1. INTRODUCTION

To increase the yield of hydroelectric power plants, the combination option with floating photovoltaic panels or in fixed installation can be used if there is water gloss or unused side spaces. In many situations, it is possible to discharge the electricity produced through the existing electrical substations at hydropower plants, provided that they have unused installed capacity or that the two sources interconnected through the stations operate alternatively [7]. During the day when it is sunny, it will work on the production side from the photovoltaic panels and at night on the generator side with the hydraulic turbines.

The purpose of the work is to analyze the possibilities of mounting floating or fixed photovoltaic panels on the reservoirs and their edges for three hydropower plants that belong to the county's hydropower system. They are located on the „Crișul Repede" river and on the „Valea Drăganului" creek.

This paper examines the benefits and technical features of floating solar power plants.

2. ASPECTS ABOUT FLOATING PHOTOVOLTAIC PANELS

Floating photovoltaic panels (FPVP) are a relatively new method of producing electricity from renewable sources. These systems can be anchored on seas, lakes, ponds, marshes, canals or reservoirs. Their great advantage is that they do not take up land, which can instead be used for agriculture. These types of installations are environmentally friendly and meet the ecological requirements set out in international regulations, contributing to sustainable energy development [9].
Countries with many photovoltaic installations are in Asia such as China, Indonesia, Japan, India, Malaysia, Thailand, Vietnam or Latin America, Brazil, Paraguay, etc or Australia [12]. Specialists estimate that in the future floating photovoltaic capacities of up to 6300 TWh can be installed at worldwide level [10]. These installations can both directly supply consumers in localities but can also be used for irrigation or pumping stations for water supply [6].
Table 1 presents a ranking of three of the largest installed capacities in floating photovoltaic panels. [14].
Installing of floating photovoltaic panels requires careful planning. Areas with adequate water depth and flow must be chosen. Environmental considerations must also be taken into account – the panels must not obstruct local fauna and flora. Maintenance is relatively easy – the panels can be removed periodically for cleaning and inspections [13].

Table 1. Largest floating photovoltaic plants [14]

Rank	Location/Country	Capacity [MW]
1	Coal mining subsidence area of Huainan City I/China	40
2	Coal mining subsidence area of Huainan City II/China	20
3	Yamakura solar power plant/Japan	13,7

Figure 1 presents a statistical situation regarding the installed power of the largest floating photovoltaic panel projects [5].

The largest installed capacity is in floating panels grouped in power plants of over 15 MWp. China has the most projects (73%).

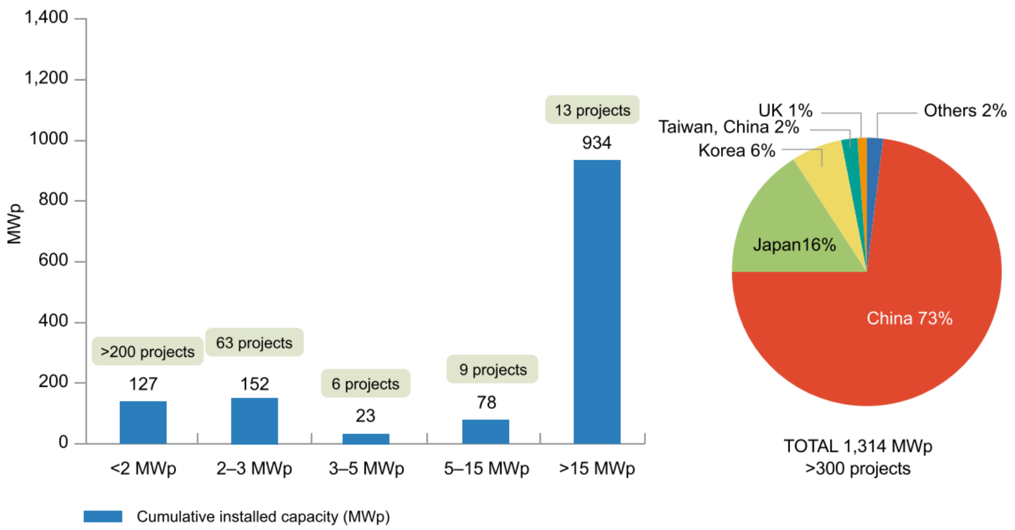


Figure 1. Installed capacity by projects and countries

Hydroelectric energy is mainly based on the construction of dams and the accumulation of water by creating large hydrological basins. Therefore, it can be said that most of the hydroelectric energy comes from the potential energy of the artificial water reservoirs created by the dam, which in many cases are equipped with a pumping system that allows the storage and reuse by pumping of water for use during peak demands [1]. Often due to low rainfall the water in the accumulation dams of the hydroelectric power plants is not in sufficient quantities to cover the entire energy capacity. In this case, the installation of floating photovoltaic panels can be used [3]. The components of a floating photovoltaic system that can be interconnected with a hydroelectric power plant and mounted on the dam reservoir are shown in Figure 2 [5].

These installations can have components that operate independently or can use existing components from the hydroelectric power plant structure with additions [2]. Figure 3 shows with graphical values an evolution of the installed capacities in floating photovoltaic power plants over the period 2010-2025[5]. Figure 4 presents photovoltaic panels installed on the reservoir of a hydropower plant (HPP) [8].

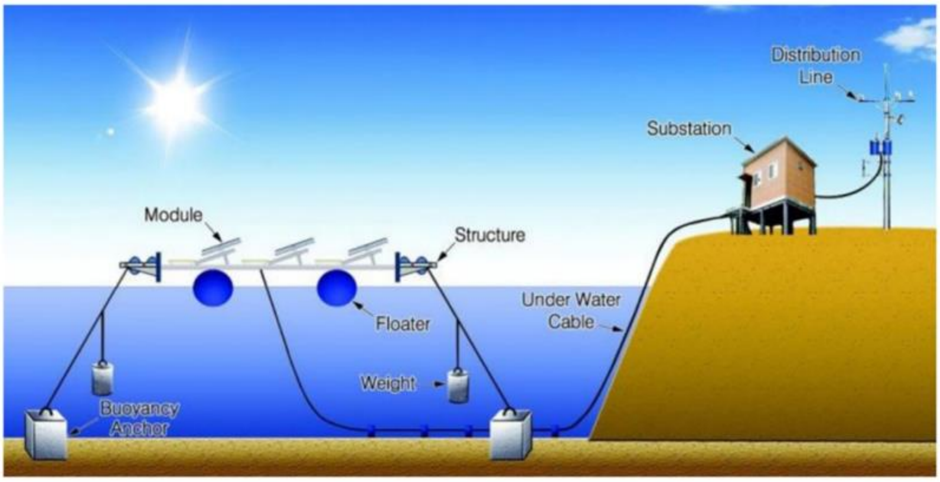


Figure 2. Structure of a floating photovoltaic system

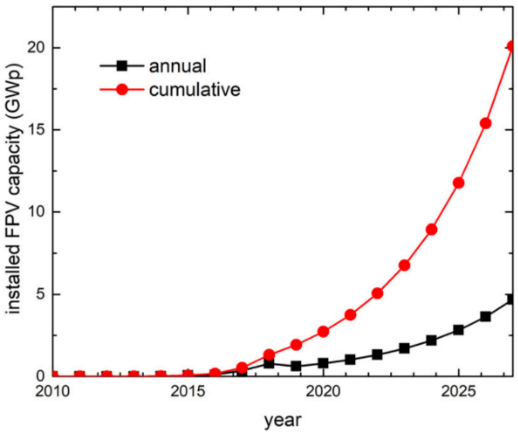


Figure 3. FPVP's Capacity evolution (GWp)

Figure 4. Photovoltaic panels on HPP dam reservoir [8]

3. INTEGRATION OF FLOATING PHOTOVOLTAIC FACILITIES IN HYDROELECTRIC SYSTEM OF BIHOR COUNTY

The first case study tests the Drăgan reservoir dam also called Floroiu, which has a height of 120 m, a width at the base in the main section of 28 m, and at the crown of 6 m, the length at the crown being 447 m and the chord length of 326 m, the body thus created incorporating a volume of concrete of approximately 470,000 cubic meters.

Lake Floroiu which is located on the „Drăganului Valley," serves the Hydroelectric Power Plant in the Remeti locality, which is of semi-buried construction type, being located on the „Bisericii Valley" and opened in 1985. It has an installed capacity of 100 MW and is equipped with 2 vertical hydropower units with a unitary power of 50 MW (synchronous generators and Francis turbines). The other two analysed cases are part of the „Cris – Aval" hydropower development in the sector delimited by the localities of Alesd and Fughiu. The hydroelectric power plants are located in the lower basin of „Crisul Repede" river and have a derivation shape and reservoirs in the Lugașu and Tileagd lakes. These power plants are equipped with vertical hydropower units (synchronous generator and Kaplan turbines by Romanian production) [11].

The Lugasu and Tileagd reservoirs consist of a reinforced concrete spillway dam, a reinforced concrete water intake for the power plants of the same name, and the reservoir dams made of local materials. The maximum retention height is 25 m, and the water volume exceeds 60 million cubic meters at Lugasu lake and 50 million cubic meters at Tileagd Hydropower Plant.

The Lugasu and Tileagd power plants have an installed capacity of 18 MW, each consisting of two hydropower units with a unitary capacity of 9 MW [11].

Figure 5 shows an aerial image of the water accumulated in the Tileagd and Lugașu dams.

Figure 5. Waters from the analyzed reservoirs

For the surfaces of lakes, the installation of floating photovoltaic panels is being considered, which increase the efficiency of hydroelectric power plants' energy production. It is especially important to take into account periods of drought when the operation of the hydroelectric power plant may be stopped.

For the purpose of the evaluation, the surface and perimeter of the investigated lakes will be determined at first. In this regard, the options in the "Google Maps" web application will be used. The surfaces rendered as graphics are delimited in the application (Figure 6) and the desired information will be generated from the functions. The following values resulted:

- Perimeter of Lugașu reservoir: P = 6,79 km;
- Surface (covering area) is S = 2,09 km ^{2}.

GPS coordinates for the searched location can also be generated. Solving this application as a case study requires minimal knowledge of using Internet search engines and dialogue with the functions offered by the interface menu of the accessed web platform.

Figure 6. Delimitation and location of the Lugașu reservoir

To highlight the photovoltaic valorization of the lake, Table 2 contains data from the proposed evaluation.

Table 2. Estimating the power of photovoltaic panels installed on Lake Lugașu

Photovoltaic panels Dimensions:2279 x 1134x 35 Unit power: 540W
Water surface of reservoir 2,09 km^2
Covering 100% for surface of 2,09km^2 • 808 panels units **Achieved power: 436,2 kW- (0,436MW)**
Covering 70% for surface of 1,463km^2 • 566 panels units **Real power: 305,64 kW (0,356MW)**

The data in Table 2 include type modulated photovoltaic panels, the chosen manufacturer

and the degree of coverage of the lake that allows fluctuations in the volume of accumulated water and the tolerance of movement on their surface of the panels.
To evaluate the efficiency of the photovoltaic panels proposed to be installed, in correlation with the zonal solar radiation and other climatic conditions.
Following the same procedure for evaluating the developable area mentioned in the case of the Lugașu dam, the delimitation for the Tileagd reservoir are shown in Figure 7.

Figure 7. Delimitation and location of the Tileagd reservoir

For Tileagd reservoir the perimeter is P = 12.9 km and the surface is S = 4.38 km^2.
Table 3 presents the results of a simulation for the energy produced by photovoltaic modules located in the analyzed area in the variant of their connection to the public grid. Under the conditions of exposure to zonal solar radiation, the best operating conditions are recorded in the months of July and August.. The type of photovoltaic cell material, energy losses, panel tilt and output data are indicated in the dedicated part of the worksheet. The chosen variant is with variable angle photovoltaic panels (they follow the rotation of the sun).
From the results in Table 3 for the Tileagd Hydropower Dam, the following can be observed:

- Dimensions of photovoltaic panels: L(length) = 2279 mm, width(l) = 1134 mm, respectively depth(g) = 35 mm;
- Number of panels to cover the entire lake surface n_p = 1695 units, respectively at coverage of 70% from slake surface, n_p =1186 units;
- At a unit power by 540 W for the panels, the electrical energy production is 0.915 MW in the first case, and 0.640 MW for case 2.

Table 3. Estimated power output for panels at Tileagd Lake

Photovoltaic panels Dimensions:2279 x 1134 x 35 Unit power: 540 W
Reservoir surface 4,38 km^2
Covering 100% for surface of 4,38 km^2 • 1695 panels units **Real power: 915,3kW (0.915MW)**
Covering 70% for surface of 3,066 km^2 • 1186 panels units **Real power: 640,44 kW (0,640MW)**

Figures 8 and 9 present the characteristics of the photovoltaic panels for the analyzed locations and the values of electricity production along with other results (the panels being considered fixed), from the operation of a segment of the proposed floating photovoltaic park. Investments in materials and auxiliary components such as floats or attachment bars have not been taken into account. These take up additional space and reduce the filling surface of the lakes. At the same time, the volume variations of the water accumulated in the dams must also be taken into account. For the Drăgan Dam, an analysis was carried out to establish the production capacity of a fixed photovoltaic system and it was found, following the results taken from the system regarding the 20 kV Drăgan Dam Substation, that the 0.4 kV ST has an own consumption of 335.463 kWh per year, and the delivery to the system is made through the connected distribution line. (LEA 20 kV, Valea Dragănului). The maximum production capacity could reach up to 400 kW and the power capacity accepted by the TSP 20/0.4 kV power transformer is 400 kVA, with positioning on the right slope where maximum efficiency prevails, as can be seen in figure 11. For example, in Table 4, the values of the monthly self-consumption indicators from the

0.4 kV substation for 2023 were calculated, based on information regarding electricity production (Table 4) the graph was created (Figure 12), respectively the power injection scheme in the distribution grid (Figure 13).

For all cases, the distribution substations may belong to the hydroelectric power plant such as the distribution lines, too.
The importance of determining the positioning of the panels has a major effect on the performance of the designed system.

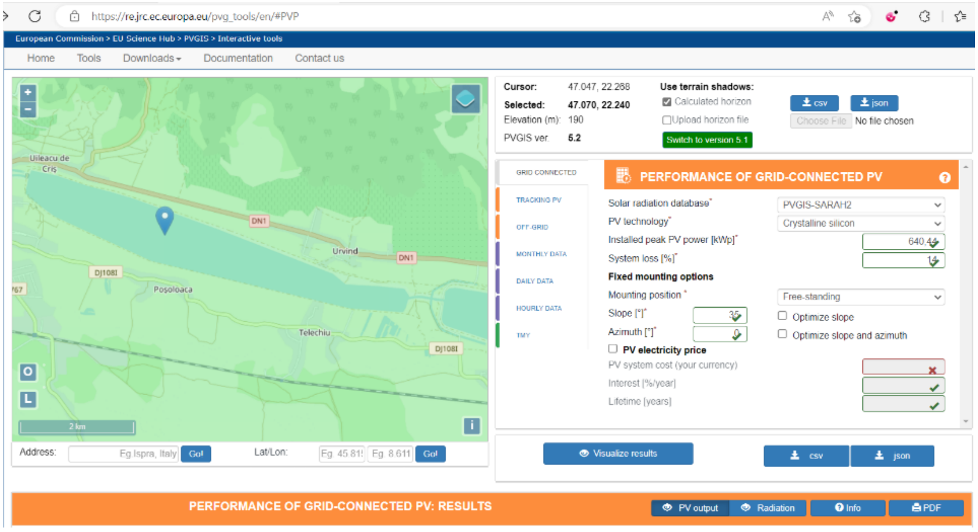


Figure 8. Solar radiation conversion efficiency parameters for Lake Tileagd

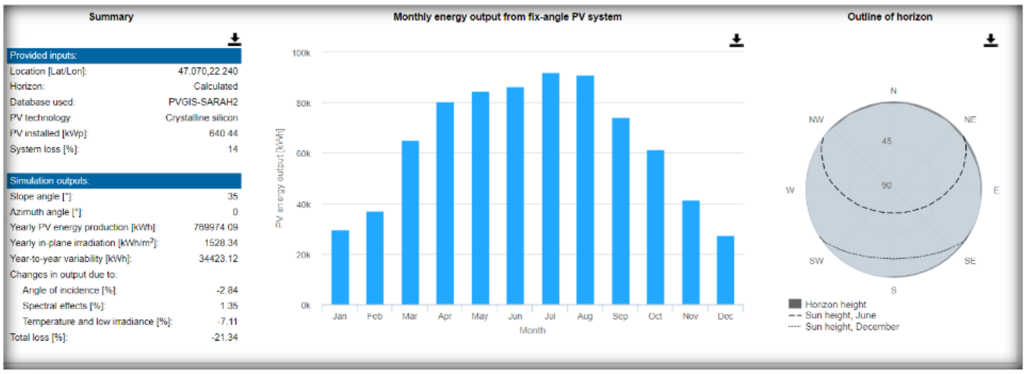
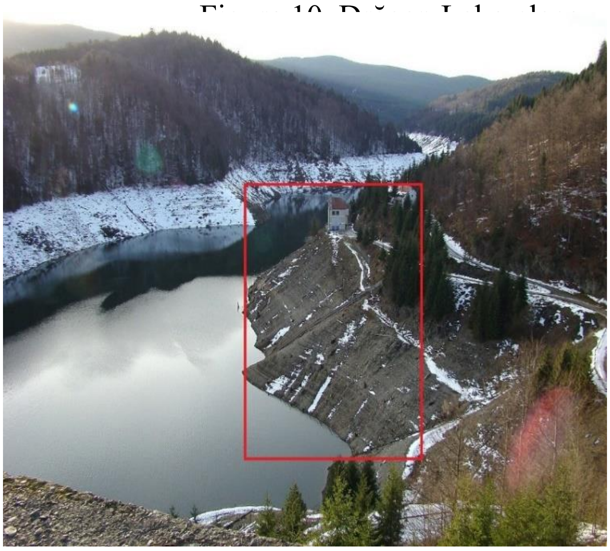


Figure 9. Energy production of panels for variable angles



Month	E_m	SD_m
January	16787,048	4874,1
February	24128,069	4877,5
Mars	36590,310	8538,0
April	42583,112	8512,0
May	41676,112	4231,3
June	44244,513	4726,3
July	48786,215	5147,5
August	48935,615	6180,5
September	39218,212	5072,4
October	35346,810	6406,9
November	22752,167	6085,6
December	11748,735	3450,8

Figure 11. Fixed photovoltaic panels location on Drăgan edges

Table 4 shows data on the monthly electricity production of the panels at the Drăgan dam.

Table 4. Electricity production for Drăgan

where: E_m is the average monthly electricity production from the defined system [kWh] and SD_m is the standard deviation of the monthly electricity production due to year-to-year variation [kWh].

For fixed photovoltaic panels, the electrical energy production is graphically presented in Figure 12.

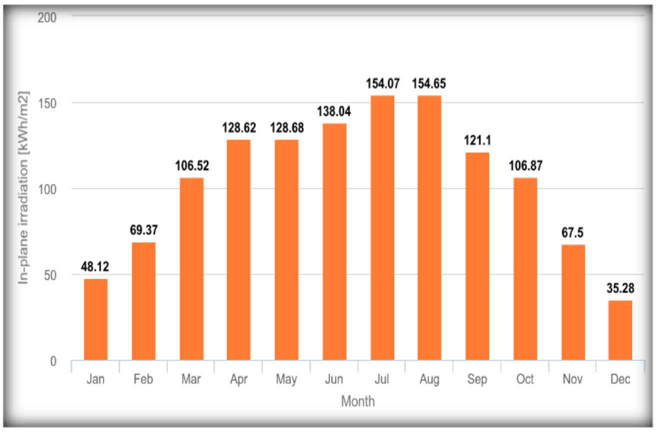


Figure 12. Monthly in-plane irradiation for fixed angle

According to angle of inclination the costs of investments and electricity production varies between 2,67 Eur/Wp at a 10° tilt and 3,09 Eur/Wp at a 40° panel tilt [4].

The scheme for fitting photovoltaic panels into the electrical energy evacuation system is presented in Figure 13.

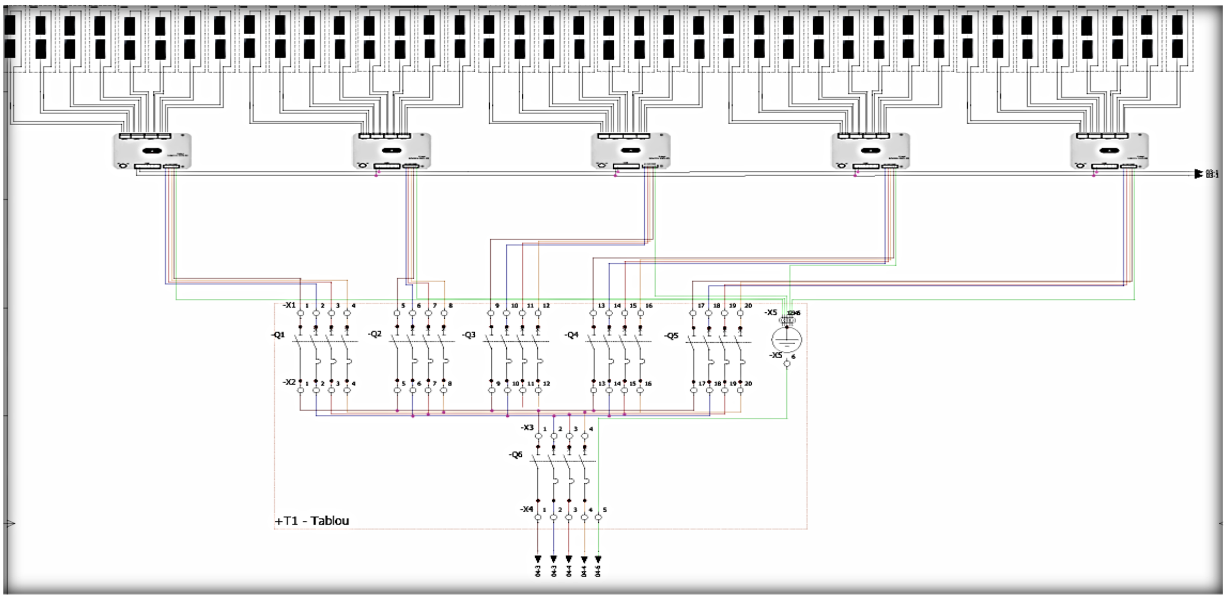


Figure 13. A scheme to connecting the FPVP at Drăgan distribution station

4. CONCLUSION

For each type of hydrological arrangement, when installing the photovoltaic panels, the arrangement possibilities, the existence of side dikes, the possibility of regulating the water in the dam or the possibilities of discharging the electricity obtained through the photovoltaic path are taken into account. At the hydroelectric power plants studied, there are escape routes to which others specific to the transformation of the direct voltage of the photovoltaic panels into alternating voltage must be added, then raising its level and connecting to the existing electrical installations in order not to make additional investments in new ones that would increase the installation price and which will have to be found in the electrical energy produced, making the amortization in a higher time.
The climatic conditions allow for the placement of floating photovoltaic panels in the chosen locations, and the technical conditions of the hydroelectric power plants allow for the takeover of the produced electricity.
Floating photovoltaic technology is long-lasting, versatile, cost-effective, and takes relative less time to install as other types. With these facilities, a country like Romania would be able to meet its electrical needs in the future so that renewable energy sources reach the usage thresholds proposed at the European Union level.

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