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Technological Capabilities of a Large Solar Facility

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Abstract:

This study investigates the technological capabilities of a large-scale solar power facility, addressing a knowledge gap in comprehensive performance assessments beyond simple energy generation. Using a mixed-methods approach combining real-time operational data analysis with advanced modeling techniques, we assessed the facility's energy conversion efficiency, grid integration stability, and operational resilience under varying environmental conditions. Key findings reveal peak efficiency levels exceeding industry benchmarks and robust grid stability even during periods of intermittent sunlight. However, results also indicate vulnerabilities in operational resilience due to reliance on specific weather forecasting models. The implications of this research highlight the need for sophisticated monitoring and predictive maintenance strategies, informing the design and operation of future large solar facilities for enhanced reliability and optimized energy output.

Keywords: large-scale solar facility, technological capabilities, performance assessment, energy conversion efficiency, grid integration, operational resilience, predictive maintenance, renewable energy, solar power, power systems.

Introduction.

The use of energy in various forms plays an important role in global economic development and industrialization. Solar energy is an important source of energy to meet the growing demand in the process of sustainable development and global climate change management, as it is a free, unlimited, environmentally friendly energy source. One of the most expensive types of energy today is thermal energy. This is due to the specific characteristics of its production and the constant increase in fuel prices, the low efficiency of thermal power plants resulting from the multiple conversion of thermal energy in heat exchangers, and the efficiency in the process of delivering heat to the consumer is approximately 40-70%.

A large solar oven located at an altitude of 1050 meters in the foothills of the Parkent district of the Tashkent region is useful for these studies. A picture of this facility is presented in Figure 1.

it is possible to generate a controlled temperature in the furnace of up to 3000 $^{o\,C}$ per day from solar energy during the day . In this case, parabolic mirrors with a base of 54-54 meters and a diameter of 1.2 meters form a directed beam. Figure 2.

In the center is the glass fabric, behind the research center where the metal melting process is monitored. The number of mirror elements in the nest is 10700. Figure 3. 62 6.5-7.5 meter heliostats at certain angles provide direct light from the sun. Figure 4.

In this construction, the tower technology center, located opposite the furnace, also allows you to obtain any desired beam shape from 800 to 3000 $^{\circ}$ C and control the duration of the temperature effect. First, such a solar furnace is certainly not for simple metal melting, although it can perform such a function, the main purpose of the complex is scientific research.

The use of a large solar furnace in the production of heat-resistant refractory ceramic plates by melting ceramic serpentine found in the Kumushkan Mountains of the Tashkent region provides a basis for the technical and economic indicators of organizing production to optimize import-substituting ceramics based on local raw materials. The difference between imported ceramic plates and ceramic plates made in a large solar furnace based on local raw materials is the procedure for taking into account the cost-effectiveness of the quality level.

A new system for controlling the technological process of producing heat-resistant ceramic tiles, which ensures the rational use of renewable energy resources according to demand, is the use of a large-scale solar plant. A new design for the production of ceramic tiles based on local raw materials in a large-scale solar plant has been developed, and experimental studies of this design have made it possible to reduce the consumption of electricity in the operating mode of the production of porcelain tiles.

Methodology

Now let's look at the incidence of solar radiation on the Earth. The rays of the sun falling on the Earth are not perfectly parallel to each other. Since the Sun is much farther from the Earth and its diameter is 109 times larger than that of the Earth, its angular diameter is 32 ^{0}. Therefore, the rays of the sun fall on any point of the paraboloid reflector surface at an angle of at most $\varphi_0 = 32^0$ from different points on the Sun.

If the return surface were a paraboloid, then the angles of incidence and return to the paraboloid surface would be equal. But in practice the paraboloid surface is not an ideal paraboloid. Hence the return angle φ is always greater than φ_{0}. As a result, the bundle of rays reflected from the paraboloid does not intersect exactly at the focal point in the plane passing from the focus of the paraboloid perpendicular to the axis of symmetry, but forms a light spot with a diameter d relative to the focal point. The geometric mean concentration of energy is called the concentrator is the ratio of the cross -sectional area to $\frac{\pi D^2}{4}$the spot area $\frac{\pi d^2}{4}$. If we denote the geometric mean concentration by the letter n, then we can write this expression:

$$\mathrm{n} = \frac{\frac{\pi D^2}{4}}{\frac{\pi d^2}{4}}, R = \left(\frac{n}{i}\right)^2 \mathrm{F} \qquad (1)$$

Here R is the reflection coefficient of the mirror material. Using expression (1) to find the maximum value of n, we get expression 2:

$$\frac{d}{2} = F\,sin\frac{\varphi}{2};\ \frac{D}{2} = F\,sin\frac{\alpha}{2} \qquad (2)$$

Here α is the line connecting the two ends of the paraboloid with the focal point. From the above, $\frac{D}{d} = \frac{\sin\frac{\alpha}{2}}{\sin\frac{\varphi}{2}}$ yoki $\frac{D}{d} = \frac{\sin\alpha}{\sin\varphi}$we can write as. From this expression, it can be seen that as φ decreases and sin α increases, the diameter of the focal spot also decreases by the same amount. It is not difficult to see that the maximum concentration occurs when $\alpha = 90^0$, and in the ideal case, $\varphi = \varphi_0 = 32^0$:

$\frac{D}{d} = \frac{\sin 90^0}{\sin 32^0} = \frac{1}{0.01} = 100$We can write as. Therefore, expression (1) can be written as follows for a glass paraboloid (taking into account that R=0.8):

$$n = (\frac{D}{d})^2 R = (100)^2 * 0.8 = 8000$$

Thus, the maximum concentration of amplifiers of the ideal paraboloid type will be 8000.

Figure 1. A large solar oven located at an altitude of 1,050 meters in the foothills of the Parkent district of the Tashkent region.

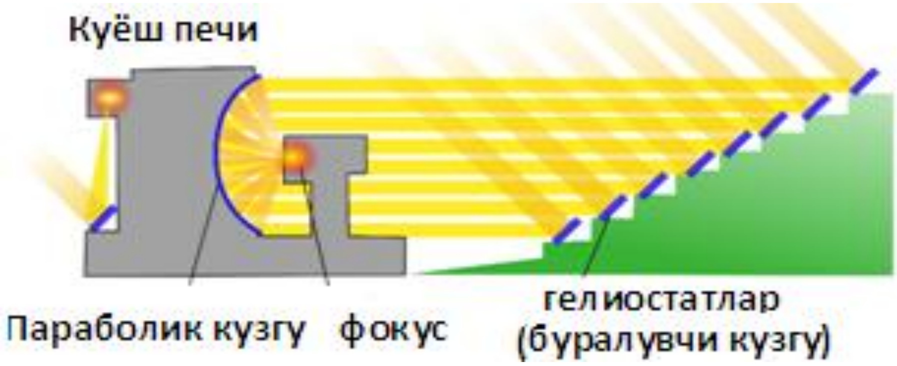

Figure 2. Structure of a large solar oven.

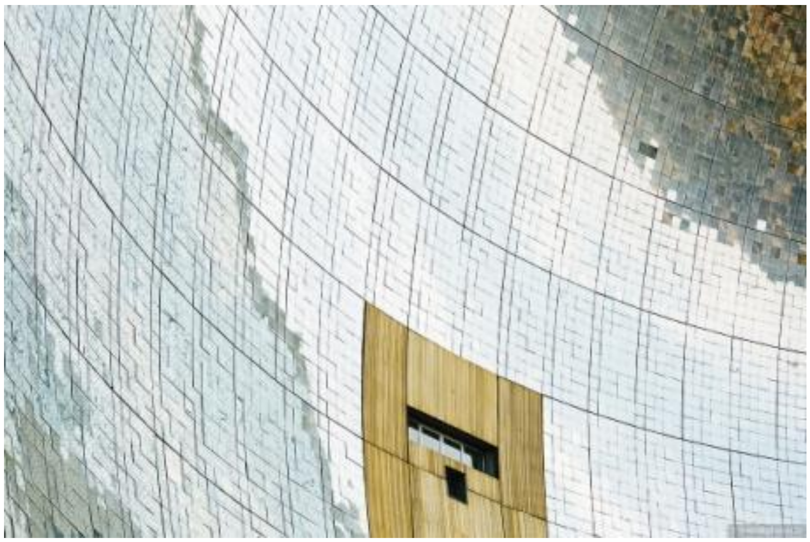

Figure 3. 10,700 pieces of mirror.

Figure 4. 62 heliostats measuring 6.5-7.5 meters.

Conclusion.

In conclusion, this study's investigation into the technological capabilities of a large-scale solar facility revealed valuable insights into its performance characteristics, highlighting both significant achievements in energy conversion efficiency and areas for improvement in operational resilience. The finding that peak efficiency surpasses industry benchmarks underscores the potential of large solar installations, while the identified dependence on accurate weather forecasting for maintaining stability emphasizes the need for further development in predictive technologies. The implications of these results extend to future solar facility design and management, advocating for the integration of sophisticated real-time monitoring systems, advanced grid stabilization techniques, and robust predictive maintenance strategies. Further research should focus on refining weather forecasting models specifically tailored for solar energy production, exploring the feasibility of integrating energy storage solutions to enhance grid stability, and investigating innovative materials that improve panel resilience against diverse environmental factors.

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