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IMPLEMENTING A SOLAR PHOTOVOLTAIC STATION IN WATERING SYSTEMS UTILIZING COMPLEX SOFTWARE

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CONTENTS

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С О Д Е Р Ж А Н И Е

IMPLEMENTING A SOLAR PHOTOVOLTAIC STATION IN WATERING SYSTEMS UTILIZING COMPLEX SOFTWARE

F.J.NOSIROV, A.S.UROQOV, G.P.ARZIKULOV, Z.A.SAYFUTDINOVA (Tashkent State Technical University, Tashkent city, Republic of Uzbekistan)*

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Abstract: *This article explores the benefits of transitioning from traditional agricultural irrigation systems to more cost-effective alternatives powered by renewable energy sources. By integrating solar photovoltaic technology into irrigation processes, significant reductions in resource wastage, estimated at 45-50%, are achievable through the implementation of drip irrigation techniques. This results in enhanced agricultural productivity. Moreover, the utilization of solar panels in green zones mitigates surface temperature increases, contributing to a 2-5% boost in electricity production. Currently, irrigation facilities primarily rely on the main energy grid. However, transitioning to renewable energy sources decreases reliance on non-renewable fuels, reduces greenhouse gas emissions, and fosters ecological improvements. Photoelectric stations offer an eco-friendly and economical electricity source, enhancing the Republic's power system. Grid-connected photovoltaic plants alleviate strain on the grid and fully satisfy the energy demands of irrigation pumps. Design analyses of a solar photovoltaic plant were conducted utilizing the PVsyst program to ascertain its capacity to power pumping stations and determine solar energy potential.*

Keywords: *solar energy, grid-connected photovoltaic plant, irrigation, pumping, drought, ecology, PVsyst, metenorm*

Annotatsiya: *Ushbu maqolada bugungi kundagi qishloq xo‘jaligi tizimlarini tubdan yangi tejamkor sug‘orish tizimlariga o‘zgaritish, sug‘orish uskunalari talab qiladigan elektr energiyasini qayta tiklanuvchi energiya qurilmalari orqali qoplash va uning ko‘rsatadigan ijobiy ko‘rsatgichlari o‘rganildi. Tomchilatib sug‘orish orqali sug‘orish maydonlari talab qiladigan sug‘orish resurslari isrofini 45-50% ga kamaytirish va qishloq xo‘jaligi ekinlarini yetishtirishdagi hosildorlikni oshishini ko‘rishimiz mumkin. Qolaversa, yashil zonalarga o‘rnatilgan quyosh panellari sirtida harorat oshishi kamayadi. Elektr energiyasi ishlab chiqarish 2-5 % ga ortadi. Bugungi kunda sug‘orish inshootlari asosiy tarmoqqa ulangan holda faoliyat ko‘rsatadi Asosiy tarmoqda energiya iste’moli kamaysa, qayta tiklanmaydigan yoqilg‘ilar yoqilishi kamayadi, atmosferaga chiqariladigan issiqxona gazlari hajm ko‘rsatkichi pastlaydi, ekologik tizim yaxshilanadi. Fotoelektrik stansiyalar ekologik toza va arzon elektr energiyasi manbai hisoblanadi va ulardan foydalanish Respublika elektr tizimini yaxshilashga xizmat qiladi.. Tarmoq fotoelektrik stansiyalari tarmoqning yuklamasini kamaytiradi, sug‘orish nasoslari ta’lab qiladigan energiyani to‘laligicha qoplaydi. Nasos stansiyalari elektr energiyasini qoplash uchun PVsyst dasturi orqali quyosh fotoelektrik stansiyasi loyihalash ishlari bajarildi, quyosh energetik potensiali aniqlandi.*

Kalit so‘zlar: *quyosh energetikasi, tarmoq fotoelektrik stansiyasi, sug‘orish, nasos, qurg‘oqchilik, ekologiya, PVsyst, metenorm.*

Аннотация: *В данной статье рассматриваются преимущества перехода от традиционных сельскохозяйственных систем полива к более экономически эффективным альтернативам, работающим на возобновляемых источниках энергии. Путем интеграции солнечной фотоэлектрической технологии в процессы полива достигается значительное сокращение потребления ресурсов, оцениваемое в 45-50% благодаря использованию техники капельного полива. Это приводит к повышению сельскохозяйственной продуктивности. Более того, использование солнечных панелей в зеленых зонах снижает повышение температуры на поверхности, что способствует увеличению производства электроэнергии на 2-5%. В настоящее время средства полива в основном зависят от основной энергетической сети. Однако переход к возобновляемым источникам энергии снижает зависимость от нефтяных топлив, уменьшает выбросы парниковых газов и способствует экологическим улучшениям.*

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Фотоэлектрические станции предлагают экологически чистый и экономичный источник электроэнергии, улучшая энергетическую систему Республики. Подключенные к сети фотовольтаические установки снижают нагрузку на сеть и полностью удовлетворяют энергетические потребности насосов для полива. Проектирование солнечной фотоэлектрической установки проводилось с использованием программы PVsyst для определения ее способности обеспечивать энергией насосные станции и оценки потенциала солнечной энергии.

Ключевые слова: *солнечная энергия, подключенная к сети фотовольтаическая установка, полив, насос, засуха, экология, PVsyst, метенорм.*

Introduction

Since the onset of the 19th century, non-renewable natural resources such as oil, gas, and uranium have been utilized as primary energy sources. Thus far, these non-renewable resources have comprised nearly 90% of the global energy system. Emissions of various gases and harmful substances from conventional power plants have exerted significant environmental impacts.By 2024, the conservation of water resources, freshwater scarcity, and drought are projected to emerge as primary concerns for numerous regions worldwide. Moreover, the ongoing growth of the population in our Republic is amplifying the demand for water resources. The escalating population necessitates increasing investments in agriculture annually, contributing to poverty alleviation efforts in developing countries. Notably, the primary focal points on the agenda encompass achieving food security, enhancing nutrition, and fostering economic growth and development [8,9,10]. Concerning water supply, merely 20% of the water resources utilized by the Republic of Uzbekistan are sourced within its territorial boundaries. The remaining 80% originates from neighboring Tajikistan and Kyrgyzstan and is integrated into the water resources of the Republic.

Observations of temperature dynamics in the republic indicate a yearly increase of 0.22 C° in maximum temperature and a decrease of -0.36 C° in minimum temperature. Extrapolating from these findings, it is projected that after 20 years, the average annual temperature in the northern part of the republic will rise by 2-3 C°, while in the southern part, it will increase by 1 C°. This climate change scenario is expected to lead to a 10-15% rise in water evaporation from water surfaces and a 10-20% increase in water usage due to elevated rates of plant transpiration and irrigation. Consequently, this would result in an average rise in water consumption by 18%.[18,19,20]

Water resource sustainability in the republic is facing challenges in two main directions: firstly, the inadequacy of clean drinking water for the population and significant issues in supplying water resources for agricultural purposes. There are approximately 4.3 million hectares of arable land in the country (the total irrigated area in Central Asia is 7.9 million hectares, with Uzbekistan's share being approximately 55%). Ninety percent of the country's water resources are utilized in agricultural production. As noted, approximately 20% of the water used in the country is sourced within the borders of the republic, while the remaining 80% is sourced from transboundary rivers - the Amu Darya and the Syr Darya. On average, 44-48 billion m^3 of water are used annually in the country, with the majority, or 85%, allocated for agricultural irrigation purposes. According to experts, at present, 46 billion m^3 of water are utilized for 3.2 million hectares of land, with 60% of it supporting crop cultivation. Approximately 23% of the total 180 thousand kilometers of irrigation networks are concrete-lined and have remained largely unchanged for 30-35 years. However, efficient utilization of water necessitates the implementation of water-saving technologies, particularly through the adoption of drip, sprinkler, and plastic film and tube-based irrigation methods.[4,19] Drip irrigation is a method of irrigation where water is delivered directly to the root zone of the plant in quantities equal to its demand. Unlike other irrigation methods, drip irrigation supplies water to the plant along the root zone in a controlled manner. Areas where crops are located within the irrigation field are uniformly irrigated. Excessive soil moisture does not occur, and erosion is minimized. [15,16]

In drip or sprinkler irrigation systems, pump units are utilized to generate the required pressure in the system and deliver the necessary amount of water to each point of the system.Drip irrigation systems are widely used in agricultural fields based on the location, size, and type of crops. Various types of pump units with different power ratings, which operate on electric power, are extensively employed in these systems.However, due to the conventional placement of agricultural consumers far from the grid, significant energy losses, incorrect metering of consumers, and other shortcomings in energy accounting are common in rural electrification systems.These deficiencies exacerbate the level of CO_2 emissions and contribute to the increase in the carbon footprint of the energy produced by thermal power plants.To mitigate losses in electric energy transportation, the establishment of nearby photovoltaic power stations for irrigation areas is being considered.The construction and integration of photovoltaic stations into the grid contribute to the optimization of the Republic's energy system. [7,13,17]

Research Methods and the Received Results

To develop a photovoltaic station project, it is necessary to calculate the solar energy resources for the area where the station is located. This factor is considered necessary for calculating the installed capacity of the station. At a given point on the Earth's surface, denoted as A(φ^0,ψ^0), the solar energy total potential concept typically refers to the average annual amount of solar radiation received on a horizontal receiving surface of 1 square meter over the course of one calendar year. This is denoted E^g_{val} = ($\frac{kW*hour}{m^2 year}$) For all territories of FIC (MDH) countries, we utilize the well-known Angstrem formula for calculating E^G_{val} *(S)* and E^G_{val} for an area S (km^2) based on average monthly or average daily solar radiation data at point A(φ^0,ψ^0).

$$E^G_{fakt}\,(\Delta t) = E^G_{ya}(\Delta t) * (a + b * \frac{T^{fakt}_{CC}}{T^0_{SS}}) \qquad (1)$$

In this context, $E^g_{fakt}\,(\Delta t)$ represents the average annual value of solar radiation, expressed in kilowatt-hours per square meter $\left(\frac{kW * hour}{m^2}\right)$, or simply kilowatt-hours (kW * hour), received on a horizontal surface area for a given S (km^2) over a period of Δt, which can be either 1 month or 1 day. The expression $E^g_{ya}\,(\Delta t)$ represents the solar radiation received on a horizontal surface area, expressed in kilowatt-hours per square meter $\left(\frac{kW *hour}{m^2}\right)$ or simply kilowatt-hours (kW * hour), during a period Δt (which can be either 1 month or 1 day) under clear open skies when $E^G_{\Sigma}(\Delta t) = E^G_{pr}(\Delta t)$. It is calculated using the following formula:

$$E^G_{ya}(\Delta t) = R^G_{pr}(\Delta t) \cdot cos\theta(\Delta t) \cdot \Delta t \qquad (2)$$

In this context, $R^G_{pr}(\Delta t)$ represents the average inreval power of the solar radiation received on a receiving surface in a normal orientation, expressed in watts per square meters (W/m^2). It is derived from the following formula:

$$R^G_{pr} = R^G_{pr}(AM1) \cdot \left(\frac{R^G_{pr}(AM1)}{R_0}\right)^{\text{AMm}-1} = 1000 \cdot \left(\frac{1000}{1360}\right)^{\text{AMm}-1} \qquad (3)$$

in this context, $R^G_{pr}(AM1)(\frac{W}{m^2})$ represents the standart interval power of solar radiation for a horizontal receiving surface at sea level in the southern latitudes of the Earth under clear atmospheric conditions. R_0 (W/m^2) = 1360 W/m^2 – this denotes the solar radiation flux incident on a unit area (1 m^2) of a solar collector at the boundary of the Earth's atmosphere, also known as solar constant or solar irradiance. The determination of atmospheric mass or the optical mass of the atmosphere is as follows:

$$m(\Delta t) = \frac{2}{\sqrt{cos^2\theta(\Delta t) + \frac{2 \cdot L_a}{r_3} + cos\theta(\Delta t)}} \cong \frac{2}{\sqrt{cos^2\theta(\Delta t)} + 0.06 + cos\theta(\Delta t)} \qquad (4)$$

value of $cos\theta(\Delta t)$ (according to 2) is calculated using the following formula:

$$cos\theta^0(\Delta t) = \sin\delta^0(\Delta t) \cdot sin\varphi^0 + cos\delta^0(\Delta t) \cdot cos\varphi^0 \cdot \frac{sin\omega_c}{\omega_c} \qquad (5)$$

Here, $cos\theta(\Delta t)$ (*degr,*) represents the average inclination angle of solar incidence during the time interval Δt. $\delta^0 = \delta^0(\Delta t)$ denotes the solar decliniation, determined within the time interval Δt using the Kupper formula:

$$\delta^0(\Delta t) = \delta_0 \cdot \sin\left(\frac{360}{365} \cdot (284 + n)\right) \qquad (6)$$

here, $\delta_0 - 23^0 27' = 23.45^0$

In practical applications worldwide, the modified version of the Angstrem formula as presented above is often utilized, employing the Pejdo formula for its refinement.

$$E^G_{fact}(\Delta t) = E^G_0(\Delta t) \cdot \left(a + b \cdot \frac{T^{fact}_{cc}}{T^0_{ss}}\right) \qquad (7)$$

The total solar energy resource value for the given point A(φ^0,ψ^0) is increased to the area S (m^2) per square meter [1,3]. In general, the energy received by the receiving surface can be determined using the following formula:

$$W_m = E_0 \cdot S_m \qquad (8)$$

The energy produced by solar panels depends on their installed orientation relative to the angle of incidence of sunlight, which varies seasonally. Solar panels are oriented once a month according to the angle of incidence relative to the tilt angle of the panel surface. This is determined by the following formula:

$$\beta_0 = \varphi - \delta_0 \qquad (9)$$

In this context, φ represents the geographic latitude of the region, while δ_0 denotes the solar declination for the given month. The solar declination is determined using the Kupper formula as follows:

$$\delta = 23.45 \sin\left(360\ \frac{284+n}{365}\right) \qquad (10)$$

According to the (9), for the winter season in Tashkent city (with a geographic latitude of 41°15'5"52), the optimal tilt angle can be determined as follows:

$$\beta_0 = 41° - (-20.7°) = 61.7°$$

In the same manner, the optimal tilt angle for the summer season can be calculated as follows::

$$\cos\delta = \frac{\cos(23.5°) + \cos(18.5°)}{2} = 21.1°$$

$$\beta_0 = 41° - 21.1° = 19.9°$$

According to the seasonal variations, the optimal tilt angle for installing solar panels relative to horizontal flatness is as follows: 62° in winter, 41° in spring and autumn, and 20° in summer [2]. For Tashkent city, the installation of fixed structures is recommended within the range of 38° to 44° tilt angle. The useful work coefficient of solar panels depends on radiation. At Standard Test Conditions (STC) where solar irradiance E_0 = 1000W/m^2, temperature T = 25^{o}C, and air mass (AM = 1.5 , the solar panel generates its maximum electrical energy. The variation in radiation or temperature affects the electrical energy output of photovoltaic panels. An increase in temperature leads to a decrease in the voltage output of the solar cells, which in turn affects the overall electrical energy generation. Figure 1 illustrates the change in the Volt-Ampere characteristics of the photovoltaic battery at temperatures of T=25°C and T=60°C.

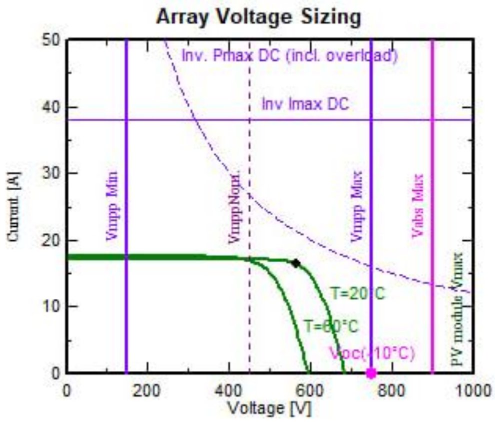

Fig. 1 The temperature dependence graph of the Volt-Ampere characteristic

Let's examine the energy properties of the photovoltaic panel. The nominal power of the photovoltaic panel, denoted as R_n , is calculated as follows:

$$R_n = U_{o.c} \cdot I_{sc} \cdot \xi = U_n \cdot I_n \quad (11)$$

In this context, $U_{o.c}$ represents the open-circuit voltage, I_{sc} denotes the short-circuit current, and ξ signifies the fill factor, which is the Volt-Ampere characteristic filling coefficient.

$$\xi = \frac{U_n \cdot I_n}{U_{o.c} \cdot I_{sc} \cdot \xi} \quad (12)$$

According to the (12) $\xi = 0.7 - 0.82$.

Based on the given values of $U_{o.c}, I_{sc}, U_n, I_n$ the useful work coefficient of the solar panel is calculated as follows:

$$\eta = \frac{U_{x.x} \cdot I_{sc} \cdot \xi}{E_0 \cdot S_m} \cdot 100\% \quad (13)$$

Through equation (13), it is possible to observe the impact of E_0 on the useful work coefficient [5].

The installation of solar panels in open fields and areas with regular sunlight supports active solar irradiation and harnesses normal radiation exposure. The utilization of photovoltaic stations in agricultural fields yields the intended outcome. Within agricultural irrigation systems, pumps are directly connected to the grid for operation. The primary function of the pump is to deliver water from the water source (well or river) to the water reservoir for irrigation. The water tank supplies irrigated areas with water. It is recommended to use solar photovoltaic stations to generate the electrical energy required for pump operation.Below, the integration scheme of the photovoltaic system with the irrigation system is presented in the figure 2.

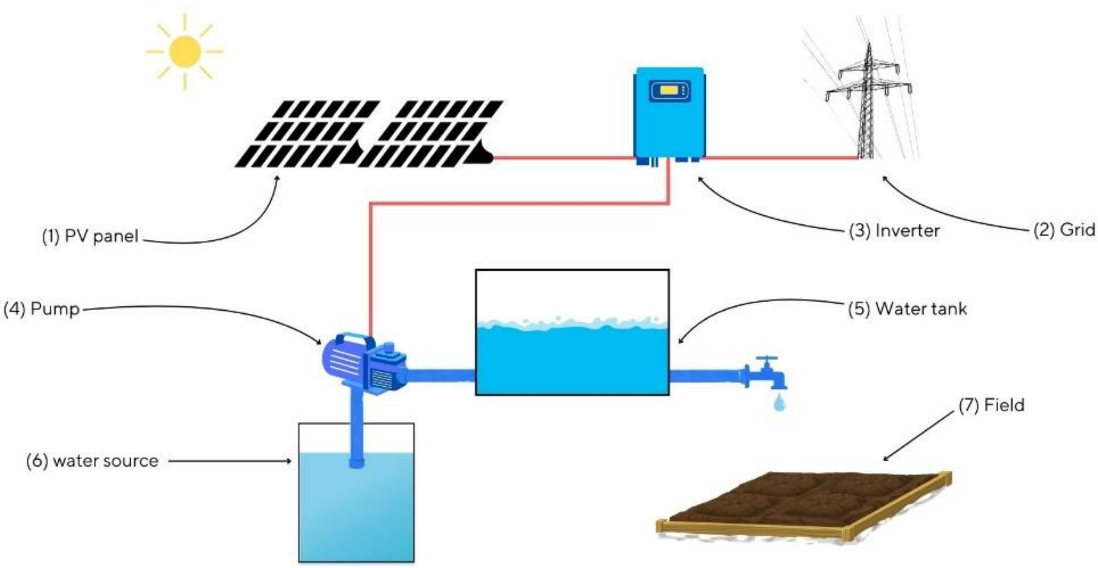

Fig. 2 Scheme of stand-alone PV pumping system
Here, 1- PV panels, 2-grid, 3-inverter, 4-pump, 5-water tank, 6-water source, 7-field

The main objective of the system is to develop new algorithms to supply the energy required for the pump through photovoltaic (PV) to meet the demand for water during the irrigation period. This algorithm encompasses the efficient and cost-effective production of energy, minimizing waste during the irrigation period. In irrigation, photovoltaic pump systems utilize two methods: "real-time" and "pumping" methods. In the "real-time" method, the pump operates using solar energy during available sunlight hours to fill the water reservoir (tank). In the "pumping" method, electrical energy is stored in batteries and can be used to pump water during the night. We employ the "real-time" method. To fill the water reservoir (tank) according to the area to be irrigated, we select a pump that consumes 7 kW of electrical energy. Considering an inverter efficiency coefficient of k=1.2, we determine the required inverter power as follows [11,6,14]:

$$Q_{in}=Q_{c(r)} * k \tag{14}$$

Geographical Site
Tashkent
Uzbekistan

Situation

Latitude	41.26 °N
Longitude	69.22 °E
Altitude	426 m
Time zone	UTC+5

Monthly Meteo Values

SoTashkent_Nasamod_TMY.SIT -- Toshkent. 2023

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	1.87	2.70	3.93	5.37	6.65	7.54	7.32	6.61	5.29	3.68	2.32	1.63	4.58	kWh/m²/day
Horizontal diffuse	0.73	1.02	1.42	1.78	2.00	1.95	1.87	1.57	1.26	0.98	0.76	0.65	1.33	kWh/m²/day
Extraterrestrial	4.06	5.61	7.51	9.56	10.99	11.61	11.34	10.18	8.34	6.28	4.48	3.62	7.81	kWh/m²/day
Clearness Index	0.461	0.481	0.523	0.562	0.605	0.650	0.646	0.649	0.634	0.586	0.518	0.450	0.587	ratio
Ambient Temper.	-3.0	-2.0	5.0	12.6	20.5	25.4	27.2	25.2	20.2	11.7	5.8	-1.0	12.3	°C

Fig. 3 Monthly Meteo Values obtained from Meteonorm

For the design of solar photovoltaic stations, we utilize the PVsyst software. PVsyst is a sophisticated software tool designed for the analysis, measurement, and evaluation of complex solar photovoltaic systems. It is specifically tailored for the design of solar photovoltaic stations with pumps, connected to the network, and operates beyond the network. It incorporates extensive databases of weather conditions and solar photovoltaic system components, facilitating comprehensive analysis. PVsyst is preferred by engineers, researchers, and practitioners because it can import weather data and personal information from various sources. The initial data for the PVsyst software package is obtained from NASA-SSE and Meteonorm meteorological sources. The Meteonorm database collects weather data from over 1200 weather stations worldwide, with monitoring periods ranging from 10 to 30 years. To achieve the highest accuracy in data approximation, Meteonorm interpolates values from the three nearest weather stations located at the point of interest. PVsyst allows you to add data to its database, providing flexibility and customization options [12,22].

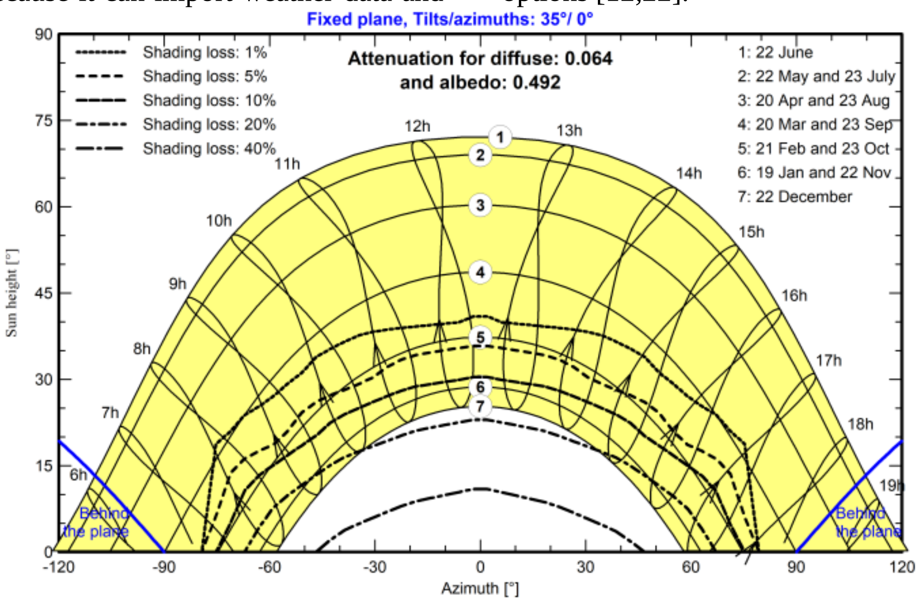

Fig. 4 Sun paths (Height/Azimuth diagram)

According to the Sun path diagram (Height/Azimuth diagram), polycrystalline silicon photovoltaic panels are installed at a fixed inclination angle of 35° relative to the horizon, with a precise orientation towards the azimuth.

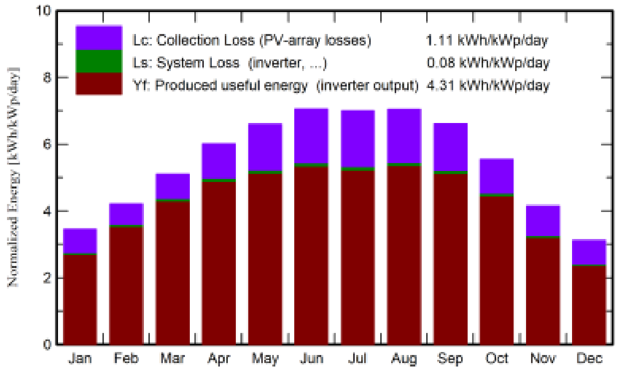

Fig. 5 Normalized productions (per installed kWp)

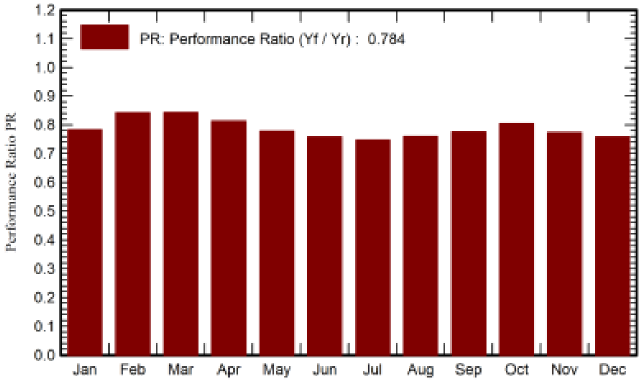

Fig. 6 Performance Ratio PR

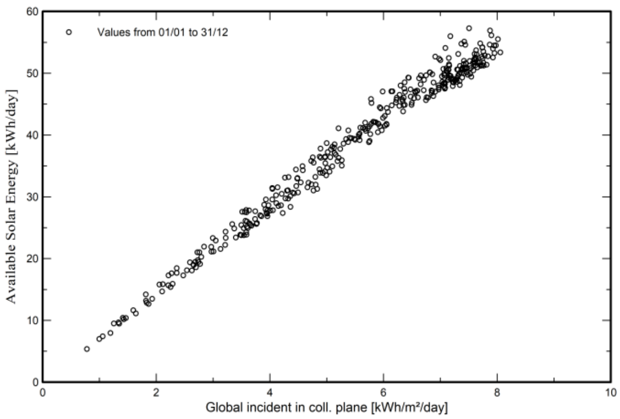

Fig. 7 Daily Input/Output diagram

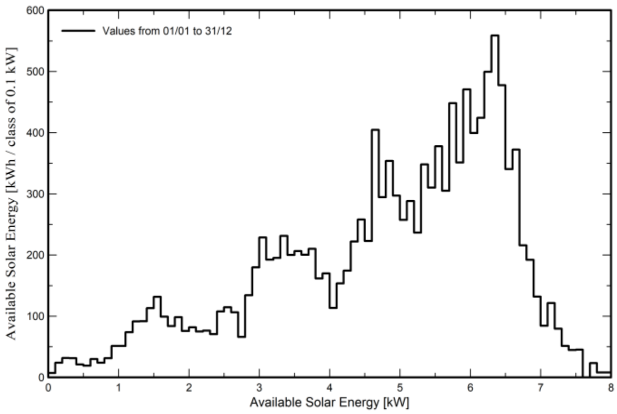

Fig. 8 System Output Power Distrbution

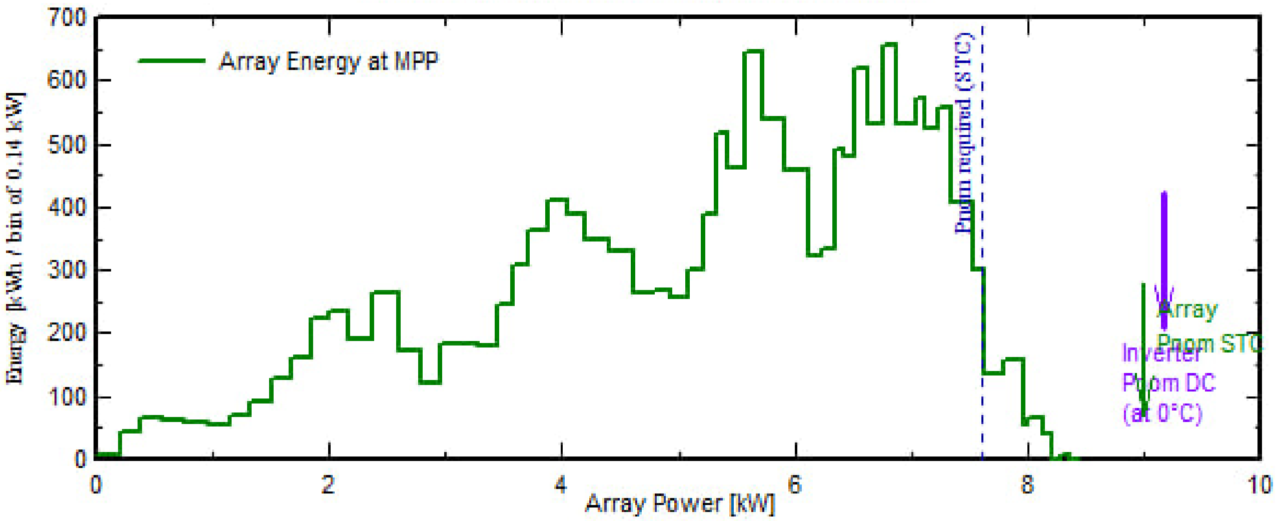

Fig. 9 Power sizing: Inverter output distribution

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_User kWh	E_Solar kWh	E_Grid kWh	EFrGrid kWh
January	58.0	22.60	-3.00	107.0	86.4	769	5654	754	0.000	4900
February	75.6	28.60	-2.00	117.8	104.0	910	5107	893	0.000	4214
March	121.8	44.00	5.00	158.2	146.3	1224	5654	1200	0.897	4455
April	161.1	53.40	12.60	180.5	167.4	1348	5472	1322	0.158	4150
May	206.1	62.00	20.50	204.5	189.1	1460	5654	1432	0.000	4222
June	226.2	58.50	25.40	211.6	195.3	1472	5472	1443	0.000	4029
July	226.9	58.00	27.20	217.1	200.3	1489	5654	1460	0.000	4194
August	204.9	48.70	25.20	218.5	203.0	1522	5654	1495	0.000	4160
September	158.7	37.80	20.20	198.3	184.6	1410	5472	1384	0.000	4088
October	114.1	30.40	11.70	171.7	156.4	1266	5654	1244	0.000	4410
November	69.6	22.80	5.80	124.4	103.8	883	5472	866	0.000	4606
December	50.5	20.10	-1.00	96.5	76.0	673	5654	659	0.000	4996
Year	1673.5	486.90	12.38	2006.1	1812.8	14424	66576	14151	1.054	52425

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_User	Energy supplied to the user
T_Amb	Ambient Temperature	E_Solar	Energy from the sun
GlobInc	Global incident in coll. plane	E_Grid	Energy injected into grid
GlobEff	Effective Global, corr. for IAM and shadings	EFrGrid	Energy from the grid

Fig. 10 Balances and main results

Conclusion

As a summary, it is important to emphasize that renewable energy sources, based on recurring energy sources, provide a significantly lower environmental impact compared to non-renewable sources. They are also considered cost-effective in terms of operation. Utilizing drip irrigation systems in countries under arid conditions is being considered to conserve water resources. With this method, it is possible to reduce water wastage by 40-45% in our Republic. Most of the pumps used for water collection in drip irrigation systems operate directly from the grid. The recommended solar power station with a 9 kW hourly energy consumption perfectly meets the demand for electrical energy in irrigation fields. The installation of photovoltaic panels at an optimal tilt angle of 35° in two rows, with a distance of 1.5 meters between rows, reduces solar radiation losses by less than 8.2%. The electricity generation from photovoltaic panels installed in agricultural fields increases by 3%. The construction of the solar power station results in an annual surplus of approximately 3,193 kW of energy, with an annual transmission of around 16,517 kW of electrical energy to the grid. The short payback period of the investment ensures the growth of these values.

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ELECTROMAGNETIC FIELD MODEL AS A SOURCE OF WATER CAVITATION ENERGY

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Abstract: *The article investigates numerical models of cavitation processes in water, fluid flow taking into account process to determine the optimal parameters for the operation of the device. A mathematical model of a rotating electromagnetic field for designing a rotary vortex generator based on cavitation processes in water is considered. The interaction of charged particles is considered in the article, which made it possible to determine the types of oscillatory processes. The study of the rotating electromagnetic field made it possible to determine the vibrationally rotational motion of molecules, which are the basis for obtaining thermal energy. In addition, describes electromagnetic methods of wastewater treatment, which showed that electromagnetic waves change the structure of hardness salts to form a brittle aragonite form of calcium carbonate. At the same time, a strong mixture of amorphous deposits of hardness salts is not formed, and previously formed deposits are destroyed and carried away with the flow of water.*
Keywords*: electromagnetic field, model, decontamination, energy source, boundary conditions.*

Annotatsiya: *Maqolada qurilmaning ishlashi uchun maqbul parametrlarni aniqlash uchun jarayonni hisobga olgan holda suvdagi kavitatsiya jarayonlarining raqamli modellari, suyuqlik oqimi o‘rganiladi. Suvdagi kavitatsiya jarayonlariga asoslangan aylanma vorteks generatorini loyihalash uchun aylanadigan elektromagnit maydonning matematik modeli ko‘rib chiqiladi. Maqolada zaryadlangan zarrachalarning o‘zaro ta'siri ko‘rib chiqiladi, bu tebranish jarayonlarining turlarini aniqlashga imkon berdi. Aylanadigan elektromagnit maydonni o‘rganish issiqlik energiyasini olish uchun asos bo‘lgan molekulalarning tebranish harakatini aniqlash imkonini berdi. Bundan tashqari, elektromagnit to‘lqinlar qattiqlik tuzlarining tuzilishini o‘zgartirib, kalsiy karbonatning mo‘rt aragonit*

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