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Extracting Technical Specifications of a Solar Panel Type to Design a 10 MW Hybrid Power Plant

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ABSTRACT

This paper focuses on the design of a 10 MW hybrid power plant using the technical specifications (data sheet) of an industrial solar panel. The main purpose was to find out the exact electrical properties of the solar panel specialy with conjunction to its temperature, to optimize overall output energy. We first describe the most important types of solar power plants and afterwards focus on electric plant. Subsequently, we use a suitable mathematical algorithm to find required, exact technical specifications for the photovoltaic panels from the manufacturer's general data set. After designing and optimizing the electric powered plant, explanation on the thermal power calculation is provided for using in the subsequent criteria. In the phase of thermal power design, the meteorological information related to the city of Arzoyeh of Kerman (28° 27′ 35.5″ N, 56° 21′ 56.88″ E) has been introduced into the Modelica, a powerful engineering open source software. Accordingly, a proper code was written to extract both interrelated thermal and electrical energies in the whole months during the year along with its corresponding efficiency. At the end of the work, trade off solutions for increasing the efficiency in different conditions and structures suggested, calculated, and compared.

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NOMENCLATURE

I	Current output panel(A)
V	Voltage output panel(V)
I_{pv}	Current panel(A)
I_o	Diode saturation current(A)
q	Electron number
a	Diode constant
R_s	Series Resistance
T_n	ambient temperature(Kelvin)condition test
T	Cell temperature(Kelvin)
F_R	Heat dissipation factor
F	Standard work function
N	Number of glass covers
n	Number of cell series
R_p	Shunt resistance
w	The distance between the pipe
K_p	Power dissipation factor
h_w	Wind speed
Eg	Band Gap energy
d	Diameter pipe
A	Panel Surface
$\acute{F}$	Collector efficiency
C_p	Special thermal coefficient
U_t	Coefficient of heat dissipation from the surface of the panel
Δt	Temperature difference between cell and environment
T_{amb}	ambient temperature(Kelvin)
P	Output power electric without effect of temperature
P_{out}	Output power electric with effect of temperature
Q_u	Heat absorbed by the fluid
T_H	Outlet fluid temperature
T_i	Inlet fluid temperature
$\check{N}$	Number of Panel Series
P_{pomp}	Electric pump power
SG	Density(kg/l)
h	Pump head
$\dot{m}$	Dubai Fluid

Greek Symbols

β	Angle of radiation
ε_p	Page Factor
ε_g	Glass diffusion coefficient
η_f	Total efficiency
η_h	Thermal efficiency
η_e	Electrical efficiency
η	Pump efficiency

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1. INTRODUCTION

Nowadays, due to the depletion of fossil fuels and their high prices, the use of clean power plants such as wind and solar power plants has become inevitable. Solar power plants play an important role among clean energy plants. Solar energy is a great and helpful source and due to its availability in most parts of the world, it is one of the most important kinds of these energies [1].

Solar thermal power plants are not an innovation of the last few years. Records of their use date as far back as 1878 when a small solar power plant made up of a parabolic dish concentrator connected to an engine was exhibited at the World's Fair in Paris [2]. Solar power plants have different types of manufacturing technology. Some Solar power plants convert sunlight directly to electricity, such as photovoltaic (PV) panels. Some others first sunlight convert to heat by concentrating them and then use them to generate electricity, such as stirling power plants or thermal power plants [3-5]. Concentrated solar power (CSP) is one of the most potential technologies in the field of renewable energy supply sources. In the current status, four different types of CSP plants are employed: Linear Fresnel Reflectors, Parabolic Troughs, Power tower and Stirlingdish systems. The idea of using solar energy in the Stirling engine was applied by integrating solar concentrators to the Stirling engines. dish-Stirling systems first convert the thermal energy into mechanical energy using concentrators and stirling engine, and then mechanical to electrical conversion is done using generators [4, 5]. Solar Stirling systems have demonstrated the highest efficiency when considering solar-based power generation system by converting nearly 30% of the sun's radiation into electrical energy [6]. The dish stirling technology is expected to exceed parabolic troughs technology by generating electricity comparatively at low cost and high efficiency. These systems are modular and are self-contained power generators, therefore, they can be installed inplants ranging in size from one kilowatt to 10MW [7]. Free piston stirling engines (FPSEs) draw many attentions from the researchers [8, 9]. FPSEs are known as a more advanced form of the conventional stirling engines in which the crank-shaft mechanism of the traditional engines has been eliminated. Among the known renewable energy technologies, solar energy has emerged as a viable, cost effective and commercial option for grid connected power generation [10]. Among solar power technologies, today, photovoltaic (PV) is more of interest than concentrating solar power (CSP) due to its less capital investment, simpler technology, and better economic performance [11]. According to its capacity, each solar power plant has one to several thousand photovoltaic panels. Therefore, due to the complexity of work, the design and control of a solar power plant requires its own analysis and simulation [12]. Each solar panel consists of several cells. Each of these cells has an electrical characteristic, depending on its type [13]. In fact, the photovoltaic cell is an energy conversion device and has a threshold for the solar energy gap associated with the energy gap [14,15]. In other words, the photovoltaic cell of a semiconductor diode (with binding of P, n) is exposed to sunlight [16]. Photovoltaic cells can convert between 6 to 19% of the received radiation into electricity, which is dependent on cellular technology and functional conditions of the cell. In solar cells, often more than 50% of the radiation is converted to heat and losses, which causes the cell temperature to rise above 50 ° C from the ambient temperature [17,18]. There can be two undesirable consequences: (i) a drop in cell efficiency (typically 0.4% per °C rise for C-Si cells), and (ii) a permanent structural damage of the module if the thermal stress remains for prolonged period [19]. By cooling the solar cell with circulating fluid such as water or air, electricity generation can be increased. PV/T technology with a combination of photovoltaic and solar thermal systems, can simultaneously convert solar radiation to electricity and heat. Both air and water have been used as heat transfer fluids in PV/T solar collectors which are known as PVT/air and PVT/water systems, respectively. Kern and Russell introduced the main concepts of these systems with results in for the cases of water or air as coolant in 1970's. During the past 48 years, the performance of PV/T systems has been studied using experimental and numerical methods. Hagazy [20] investigated a glazed photovoltaic/thermal air system for a single and a double pass air heater for space heating and the drying purposes. Zondag et al. [21] developed 1D, 2D, and 3D dynamical models of a multi-panel (PV/T) in 2002.

Tiwari et al. [22] evaluated the performance of PV/T air system for different climate conditions of India. Theoretical analysis and experimental validations have also been carried out. A fair agreement can be observed between the theoretical results and the practical works. Tiwari and Sodha [23] evaluated the overall performance of various configurations of hybrid PV/T thermal air collector for different weather of New Delhi, and experimental validation has been carried out.

In this paper, we first consider the electric power calculations of the solar power plant, and then the thermal calculations are presented for optimal performance. Among the new work done in this article is how to calculate the electrical characteristics of the PV panel. It is also worth noting that the proposed meteorological information is quite realistic.

2. ELECTRICAL CALCULATION

First a modeling of a PV selected, the PV contains a flow source, a diode, a parallel resistance, and a series resistance [24]. The voltage curve and current obtained from the characteristic circuit indicate low output power [25,26]. For an ideal PV cell, we have the Equation (1).

$$I = I_{pv} - I_o[e^{\left(\frac{qv}{akT_n}\right)} - 1] \quad (1)$$

The desired circuit for an ideal and practical PV device is shown in Figure 1. The exact equation for a PV device is expressed in Equation (2).

$$I = I_{pv} - I_o\left[e^{\left(\frac{RsI+V}{anVt}\right)} - 1\right] - (R_sI + V)/R_p \quad (2)$$

In Equation (2), V_t is written as Equation (3).

$$V_t = KT_n/q \quad (3)$$

The saturation flow of the diode depends on the temperature and is expressed in terms of Equation (4).

$$I_o = I_{on}(\frac{T_n}{T})^3 e^{\left[(\frac{qEg}{ak})(\frac{1}{Tn}-\frac{1}{T})\right]} \quad (4)$$

photovoltaic cell temperature, we have Equation (5) [27].

$$T = T_{amb} + Ge^{(a+bws)} + (\frac{G}{Gn})\Delta t \quad (5)$$

Panel fluctuations in terms of temperature based on Equation (6).

$$I_{pv} = (I_{pv,n} + K_I\Delta_t)G/G_n \quad (6)$$

By choosing the panel, look at Table 1, then to calculate the variables of Figure 1, ie, $\boldsymbol{R_s}$ and $\boldsymbol{R_p}$. The method of the algorithm is indicated in Figure 2. The values obtained from the calculations are equal to: $\boldsymbol{R_s}$=0.091Ω,$\boldsymbol{R_p}$=8715.5Ω,$\boldsymbol{I_o}$=36nA,$\boldsymbol{I_{pv}}$=9.572A

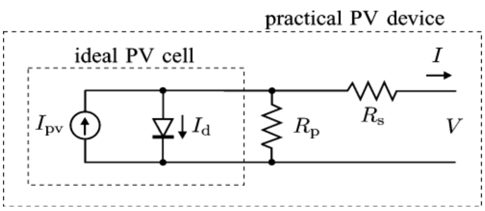

Figure 1. Circuit to a photovoltaic device

TABLE 1. Electrical data(nominal operating cell temperature)

Maximumpower electric	**P_{max}**	349.9	W
Open-circuit voltage	**V_{oc}**	46.7	V
Short-circuit current	**I_{sc}**	9.56	A
Voltage at point of maximum power	**V_{mpp}**	38.2	V
Module efficiency	**η_m**	17.9	%
Number cell	**n**	72	--

$800W/m^2$ irradiance,air temperature of 200°C,wind speed 1m/s,NOCT:450C

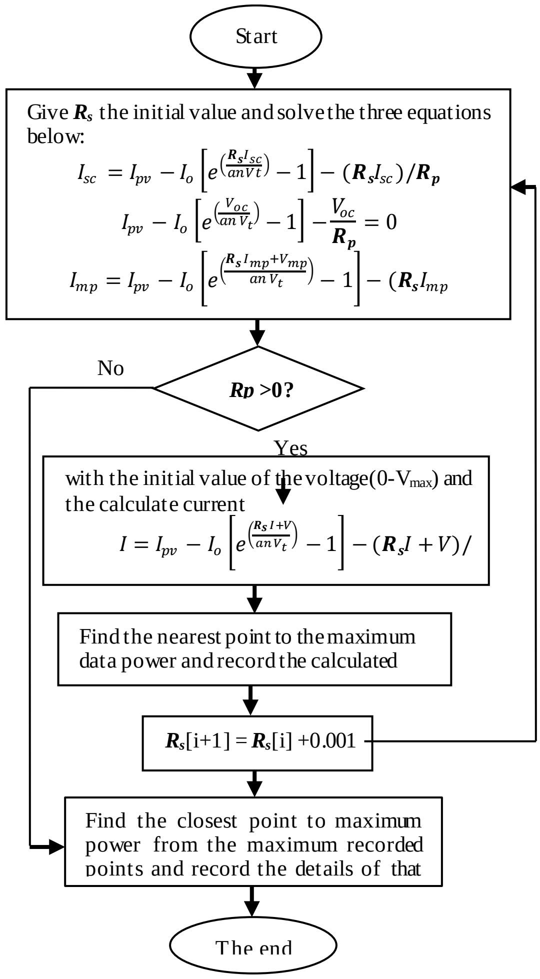

Figure 2. Application Flowchart

3. THERMAL CALCULATIONS

After entering the meteorological data of Kerman (Twelve-day average monthly for one year), we calculate the maximum output power regardless of the temperature effect. Then, using Equation (7), we calculate the power drop by considering the temperature effect.

$$P_{out} = P[1 + K_p\Delta t] \quad (7)$$

The absorption of solar panel heat has two advantages: first, it increases electrical power, and secondly, it increases the final efficiency. Using Equations (8) to (17), we calculate the amount of heat absorbed by the panel [28].

$$C = 520(1 - 0.000051\beta^2) \quad (8)$$

$$f = (1 + 0.089h_w - 0.1166h_w\varepsilon_p)(1 + 0.07866N) \quad (9)$$

$$e^* = 0.43(1 - 100/T_{cell}) \quad (10)$$

$$U_t = \left(\frac{N}{\frac{C}{T_{cell}}\left[\frac{T_{cell}-T_a}{N+f}\right]^{e^*}} + \frac{1}{h_w}\right)^{-1} + \frac{\sigma(T_{cell}+T_a)(T_{cell}^2+T_a^2)}{(\varepsilon_p+0.00591Nh_w)^{-1}+\frac{2N+f-1+0.133\varepsilon_p}{\varepsilon_g}-N} \quad (11)$$

$$m = \sqrt{U_t/K_s} \quad (12)$$

$$F = \tanh(m(w-d))/m(w-d) \quad (13)$$

$$\acute{F} = \left(wU_t[⟦U_t[d+(w-d)F]]⟧^{-1} + {C_b}^{-1} + (\pi d h_{fi})^{-1}\right)^{-1} \quad (14)$$

$$F_R = \frac{\dot{m}C_p}{AU_t}\left[1 - e^{\left(\frac{-AU_t\acute{F}}{\dot{m}C_p}\right)}\right] \quad (15)$$

$$Q_u = AF_R\left[G\varepsilon_g\varepsilon_p - \frac{P_e}{A} - U_t(T_{cell}-T_a)\right] \quad (16)$$

$$Q_u = \dot{m}C_p(T_H - T_i) \quad (17)$$

To design a ten megawatt solar power plant, we need to arrange the series and parallel solar panels. The design of this seven-inverter power plant was considered to be 1.5 megawatt. According to the specifications of the inverter, for the arrangement of solar panels, we have 25 panels in series and 163 rows in parallel. Assuming that the electrical arrangement is the same with the thermal utilization arrangement, we will consider thermal calculations. In the arrangement of the heat series obtained from a panel with a next panel, because the water temperature of the input is different in the two panels, it is slightly different. The computations in this section are that first the absorbed heat absorbed by the adsorbent pipes is calculated and then the temperature rise is calculated. In fact, this temperature is calculated on the panel to panels, the input temperature of the next cooling fluid. In the Equations (18) and (19), a change in the thermal calculation is given below [29]:

$$\acute{K}_s = \frac{AF_RU_t}{\dot{m}C_P} \quad (18)$$

$$F_{R-N-seri} = F_{R1}\left[\frac{1-(1-\acute{K}_s)^{\breve{N}}}{\acute{K}_s\breve{N}}\right] \quad (19)$$

After calculating the amount of heat absorbed in each panel and the electrical power of each panel, it is necessary to calculate the efficiency of the power plant. In the meantime, the amount of pump intake for fluid circulation is also required, this amount is calculated from Equation (20).

$$P_{pomp} = SG\dot{m}h/(368\eta) \quad (20)$$

To calculate the total power plant efficiency:

$$\eta_f = \eta_e/0.4 + \eta_h \quad (21)$$

We put the values of Table 2 in related equations.

TABlE 2. Input variables

name	amount	name	amount	name	amount
ε_p	0.95	ε_g	0.88	h_{fi}	500
β	30	N	1	K_s	0.4
$\dot{m}$	0.2	K_p	-0.0039	Eg	1.12
$\breve{N}$	17	C_p	4187	K_I	0.00048
η	%90	h	14	a	1.3
SG	1000	d	0.02	G_n	1000
A	1.94	w	0.4	K_v	-0.0031

4. RESULTS AND DISCUSSION

Since the arrival of meteorological (Figure 3 shows the average daily radiation of the city of Arzoyeh Kherman in one year) information is related to one year of work, it is time and time to choose one day from each month and bring information into temperature, wind speed, and sun radiation into the software. Choosing a plumbing to get the heat panel will reduce the pressure of the fluid and increase the consumption of pump circulation. In this design, plumbing is directly used. Figure 4 shows the total efficiency in different months of the year. The amount of monthly energy produced by the power plant is shown in Figure 5. Figure 6 shows the average temperature of the uncooled cell. Figure 7 shows the average daily radiance with the number of sunshine hours. In the panels, the amount of thermal energy thermal absorbed in the first panel and the panels is slightly different.

Comparison of the thermal energy absorbed in 1 to 25 panel per 12 o'clock one day from January is shown in Figure 8.

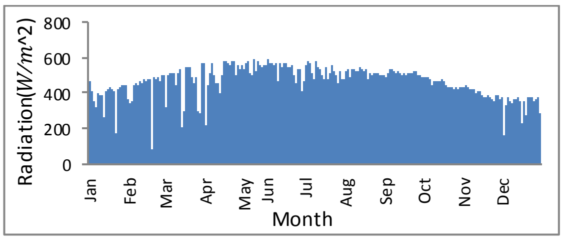

Figure 3. Average daily radiation for one year

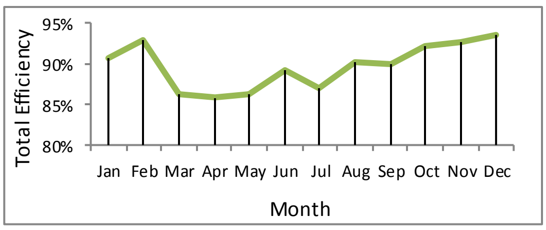

Figure 4. Total efficiency in different months of the year

In Figure 9, the electrical energy generated by panel 1 to 25 is displayed for the same hours. Thermal design for 17 and 25 panels has been performed and its efficiency is compared in Figure 10.

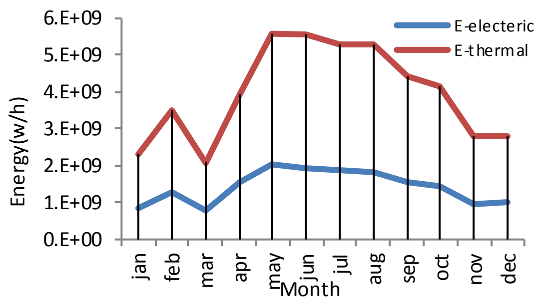

Figure 5. Monthly energy produced by the power plant

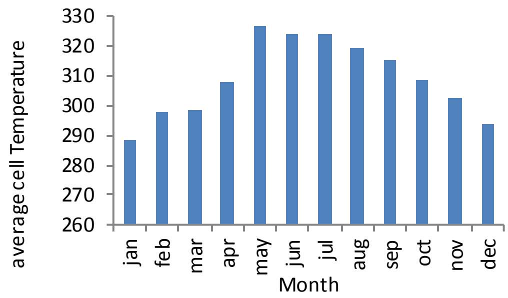

Figure 6. Average cell temperaturewithout cooling

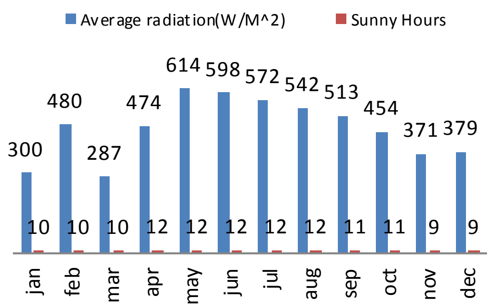

Figure 7. Average irradiance and sunny hours

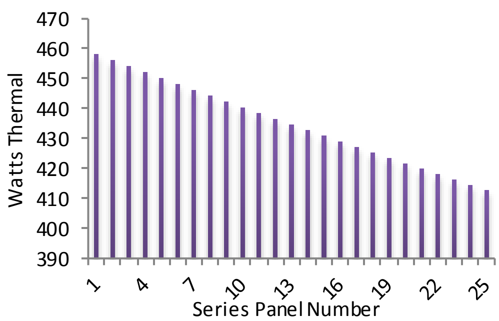

Figure 8. The amount of thermal energy absorbed by panel 1 to 25

Comparison of power plant efficiency is visible in these three models. Comparison of the efficiency of the design with 17 panels with flow 0.15 liters per second and design with 25 and 15 panels with flow rate 0.2 is shown in Figure 11.

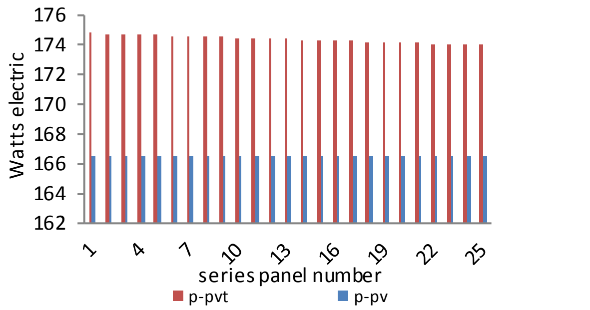

Figure 9. compar Electric power produced by panel 1 to 25 with cooling and without cooling

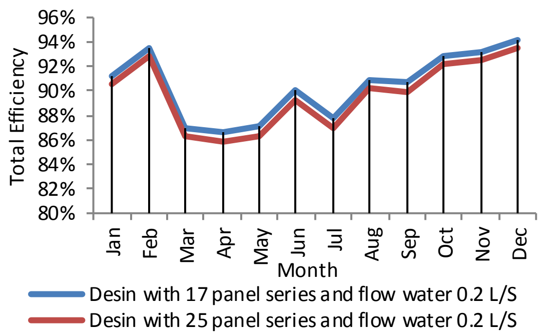

Figure 10. Comparison of thermal design 17 and 25 panels

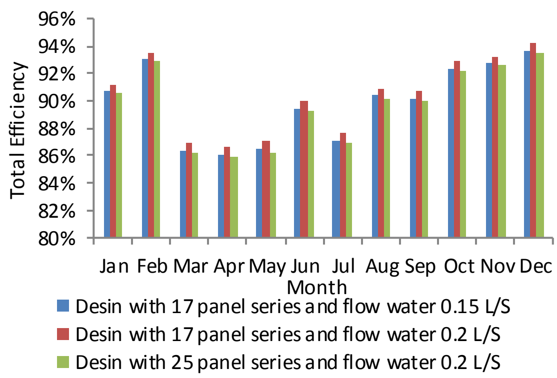

Figure 11. Comparison of thermal design 17 and 25 panels with flow rate different

5. CONCLUSION

To absorb more heat, as a result of increasing the thermal and electrical efficiency, the number of panels in the series is lower. On the other hand, reducing the number of panels to absorb more heat by each panel leads to more plumbing, as well as a greater amount of grinding, due to increased power consumption for fluid recycle. A large maze in plumbing reduces the flow rate at the outlet, which is not very applicable at the industrial scale of this type of plumbing. If the water outlet temperature of the panels in the final panel is the same for both the 25-series and 17-series, the flow rate in the 17-series model should be less than 25-series. If the flow rate is 0.15 l/s, the output water temperature is the same in both cases. this suggests that with a change in the flow rate, a higher efficiency can be achieved. If several circulating water pumps work in parallel,they can be operated with variable flux and achieve higher efficiency.

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Technical Specifications

ABSTRACT

این مقاله به طراحی یک نیروگاه هیبریدی ۱۰ مگاواتی با استفاده از مشخصات فنی(دیتاشیت) یک پنل خورشیدی صنعتی تمرکز دارد. هدف این طرح یافتن دقیق ویژگی های الکتریکی یک پنل خورشیدی با توجه به درجه حرارت آن و همچنین استفاده بهینه از گرما و الکتریسیته است. ما ابتدا به بیان انواع نیروگاه خورشیدی پرداخته و بعد از آن، نیروگاه فتوولتائیک را انتخاب و با الگوریتم ریاضی به یافتن مشخصات فنی پنل فتوولتائیک با استفاده از دیتاشیت سازنده می‌پردازیم. سپس به ارائه توضیحات در خصوص طراحی حرارتی و ارائه فرمول‌های لازم پرداخته می‌شود. پس از طراحی حرارتی اطلاعات هواشناسی مربوط به شهر ارزویه کرمان (28° 27′ 35.5″ N, 56° 21′ 56.88″ E) وارد نرم افزار مهندسی مدلیکا(یک نرم افزار منبع باز مهندسی قدرتمند) شده و باتوجه به کد نوشته شده به استخراج میزان انرژی حرارتی و الکتریکی در ماه‌های مختلف سال بهمراه راندمان آن می‌پردازد. در انتهای کار راه حل هایی جهت افزایش راندمان در شرایط مختلف بیان و راندمان خروجی در این حالت ها محاسبه و ارائه می گردد.

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