DESIGN OF A SOLAR POWERED TURBINE-DRIVEN IRRIGATION PUMP

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ABSTRACT

This project presents the design of a solar-powered, turbine-driven irrigation pump operating on the Rankine cycle using steam/water as the working fluid specifically tailored for the Altawelah region in Riyadh, Saudi Arabia. The system harnesses solar energy to pump water from a depth of 260 meters. The power plant operates between pressure limits of 0.1 and 100 bar at an ambient temperature of 15°C. Solar collectors supply the necessary thermal energy, with a total dynamic head of 266.42 meters and a power requirement of 453 kW. The solution provides a sustainable and eco-friendly irrigation method.

PROBLEM STATEMENT

Agriculture in Saudi Arabia faces critical challenges due to water scarcity, high energy demands, and reliance on fossil-fueled based irrigation systems, which increases cost, carbon emissions, and system sustainability. A solar-powered turbine-driven irrigation pump based on Rankine cycle can offer a sustainable solution. However, the following key challenges remain:

- efficient solar-to-mechanical energy conversion.
- optimization of the Rankine cycle for irrigation, integration of solar collectors, turbines, and pumps, ensuring system reliability, and meeting the high-power demand required to extract water from a 260-meter depth.

Addressing these issues is essential for creating a viable, eco-friendly irrigation system for arid regions like Saudi Arabia.

OBJECTIVES

1. Environmental Analysis: Evaluate Riyadh's environmental conditions, including solar radiation, water sources, and irrigation needs.
2. System Design: Design a Rankine cycle system that is optimized for the region.
3. Performance Analysis: Calculate system efficiency, energy balances, and performance metrics to ensure the system's feasibility.
4. Economic Feasibility: Conduct a comprehensive economic analysis to assess the financial viability of the proposed system.

MODEL

The proposed solar-powered irrigation system model is shown in Figure 1. It consists of three sub-systems: (i) the hydraulic pump system, (ii) the Rankine cycle power generation system, and (iii) the solar collector system. Solar radiation input is modeled using the ASHRAE clear sky model. The different system components are selected from commercial vendor catalogs which are designed using various design standards practiced by the industry.

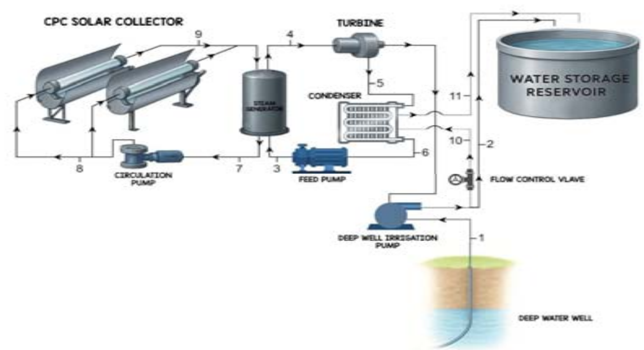

Figure 1: System model for the project

RESULTS

This section presents the detailed design results for each sub-system model. The calculations are based on the ground water data available for the Altawaleh region in Riyadh, Saudi Arabia.

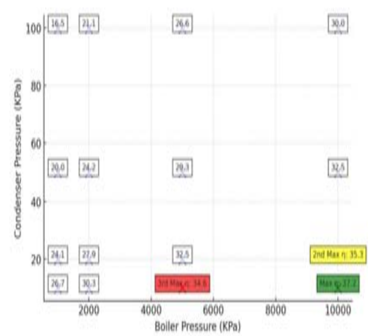

Figure 2 : Rankine cycle efficiency as a function of boiler and condenser pressures.

Table 1: Monthly solar irradiance calculations.

Month	Coefficients of Clear Sky Model			n	δ	G_{bN}	G_b	G_d	G_r	S_{max}	S_{avg}
	A (W/m²)	B	C		deg	W/m²	W/m²	W/m²	W/m²	W/m²	W/m²
Nov	1221	0.149	0.063	325	-20.44	987.6	693.7	59.30	7.05	760.0	449.1
Dec	1233	0.142	0.057	355	-23.45	996.5	664.3	54.14	6.73	725.2	416.8
Jan	1230	0.142	0.058	21	-20.14	1007	713.7	55.66	7.21	776.6	457.1
Feb	1215	0.144	0.060	52	-11.23	1017	823.1	58.16	8.26	889.5	535.3

Table 2 : Daily average solar irradiation on February 21, using ASHRAE clear sky model

LCT	LST	G_{bN}	G_b	G_d	G_r	S_{max} (G_t)	S_{avg} ($G_{t(avg)}$)
Hours	Hours	W/m²	W/m²	W/m²	W/m²	W/m²	W/m²
7:00 AM	6:53.01 AM	373.71	45.64	21.37	0.63	67.64	
8:00 AM	7:53.01 AM	795.25	270.19	45.48	2.96	318.62	
9:00 AM	8:53.01 AM	925.30	489.17	52.92	5.01	547.17	
10:00 AM	9:53.01 AM	981.89	663.77	56.15	6.75	726.67	
11:00 AM	10:53.01 AM	1008.19	778.06	57.66	7.83	843.54	
12:00 PM	11:53.01 AM	1016.96	823.06	58.16	8.26	889.48	
13:00 PM	12:53.01 PM	1011.66	795.39	57.86	7.99	861.24	
14:00 PM	13:53.01 PM	990.25	697.13	56.63	7.06	760.83	
15:00 PM	14:53.01 PM	943.02	535.87	53.93	5.53	595.33	
16:00 PM	15:53.01 PM	838.48	325.52	47.95	3.50	376.97	
17:00 PM	16:53.01 PM	536.62	94.56	30.69	1.17	126.42	
							535.33

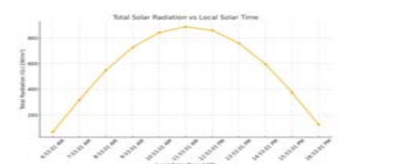

Figure 3 : Hourly total solar irradiation (G_t) on February 21, using ASHRAE model.

CONCLUSIONS

In this project, a solar-powered, Rankine cycle system is designed to operate an irrigation pump that required approximately 450 kW power to pump ground water from a depth of 260 m. It featured the use of 312 CPC solar collectors, each having an aperture area of 15.3 m². The maximum Rankine cycle efficiency for the operating pressure range is approximately 37%. A baseline economic analysis of the system reveals a capital cost of 421,125 SAR, annual operating cost of 84,225 SAR, and a net income of 147,400 SAR, yielding a 15% ROI and a 6.6-year payback period. The design is efficient, cost-effective, and eco-friendly—ideal for sustainable agriculture.

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