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Are Off-grid Solar PV Pumps a solution to Power Crisis in Agriculture– Some reflections on the initiative of New State of Andhra Pradesh

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Abstract: Electricity in agriculture for irrigation has significantly contributed to agricultural productivity growth and improved food security. In Andhra Pradesh, about 50% of irrigated area is under groundwater irrigation. Average increase of number of tube wells in Andhra Pradesh is around 50,000 per year with trends of further increase. With the state already facing a peak deficit of 6.5% and energy deficit of about 17%, providing quality and reliable power is a challenge to the State Government. Hence Government of Andhra Pradesh is planning to roll out a scheme to introduce solar agriculture pump sets. This paper aims at the design of the Solar water pumping system for irrigating the Paddy and evaluates its benefits in its life cycle giving impetus to the initiative of new state of Andhra Pradesh through a case study and suggests a road map for achieving long-term benefits.

Key words : *Crop Evaporation, Solar radiation, SAPV, Water pumping, LCC.*

INRODUCTION

The development of agriculture in the New State of Andhra Pradesh is imperative and top-priority to the state as this sector contributes to one-third to GSDP and provides employment to more than 70% of the population in rural areas. However, scarcity of electricity coupled with increasing unreliability on monsoon rains is damaging the crops thereby reducing the yield and income of particularly the small and marginal famers. Providing good quality power supply replacing untimely, erratic and highly unreliable power with low voltage is a major challenge to state to improve the crop yield, safety and convenience of the farmer. With the state already facing a peak deficit of 6.5% and energy deficit of about 17%, providing quality and reliable power is a challenging and difficult task for the government. Solar PV water pumping systems provide environmental-friendly, low maintenance alternatives for irrigation. This gives succor to the farmers who are faced with untimely, low quality power increasing the cost.

The objective of this paper is to design of the Solar water pumping system for irrigating the Paddy and evaluates its performance over its life cycle. The present study is carried out after interacting with the farmers and collecting the information in the form of a questionnaire. The objective of the questionnaire is to understand the requirements of the farmers at the ground level, present power problems and elicit the farmers opinion on the solar alternative. The study was conducted at Pedavegi mandal, West Godavari district, A.P, India. The paper is divided into six sections. The first section provides the analysis of sample data collected from the area of study. The second section determines the monthly average daily requirement of water for paddy, and the third section calculates the hydraulic energy requirement. Determination of suitable PV array sizing is done in the fourth section followed by cost analysis based on the life cycle of the Solar PV systems in the fifth section. Results and discussions are presented in sixth section with conclusions in the seventh section.

METHODOLGY:

Latitude of this area is 16.7 N and Longitude is 81.1 E. Monthly average solar radiation (MJ/m^2) is also estimated for this area at an optimal tilt angle. To design an effective Stand Alone Photovoltaic (SAPV) water pumping system, sample data has been collected from the farmers those who are irrigating the Paddy. The hydraulic energy requirement in terms of Horse Power (HP) is calculated to wet the 1 acre (0.4 hectare) land at an average head of 150 feet (nearly 45 meters) and which is compared with the HP used per acre from the sample data sheets collected from the framers. And also Life Cycle Cost (LCC) analysis is performed for cost comparison.

I. ANALYSIS OF SAMPLE DATA COLLECTED FROM AREA OF STUDY

In Table 1, data has been provided which is collected from the farmers who are irrigating the paddy fields in Pedavegi, West Godavari district, A.P. Twenty samples of data shown in the following table at a total head of nearly 45 m.

Table 1

Farmer code	Designed for the Head (m)	Size of the motor capacity utilized (HP)	Area of the land being irrigated (acres)	Utilized HP/acre	Calculated HP/acre	Actual HP needed for irrigation
F1	45	12.5	1.5	8.33	1	1.5
F2	45	15	3	5	1	3
F3	45	15	2	7.5	1	2
F4	45	15	1	15	1	1
F5	45	12.5	6	2.1	1	6
F6	45	7.5	2	3.75	1	2
F7	45	10	3	3.33	1	3
F8	45	15	8	1.87	1	8

F9	45	5	1.5	3.33	1	1.5
F10	45	10	5	2	1	5
F11	45	15	3	3	1	3
F12	45	15	8	1.87	1	8
F13	45	7.5	3	3.75	1	3
F14	45	10	4.5	2.22	1	4.5
F15	45	15	5	3	1	5
F16	45	6	4	1.5	1	4
F17	45	15	4.5	3.33	1	4.5
F18	45	12.5	1.5	8.33	1	1.5
F19	45	15	3	5	1	3
F20	45	15	2	7.5	1	2

II. DETERMINATION OF MONTHLY AVERAGE DAILY PEAK WATER REQUIREMENT

The water requirement for cultivation of the paddy depends upon the season in which it is irrigated. In India, seasons of paddy cultivation are generally classified as Rabi and Kharif. Usually Rabi season is from December to May and Kharif is from June to November. For optimum irrigation, it is essential to estimate the requirement of water from day of sowing to harvest. In the present study, monthly peak water requirement [1-2] per acre is estimated to design the system by using the following equation (1).

$$Wr = \frac{\text{Crop area} \times PE \times Kc \times Pc \times Wa}{Eu} \qquad (1)$$

Where, Wr = Peak water requirement (m^3/day)

Crop area in m^2

Pc = pan coefficient, approximately taken as 0.8

PE = pan evaporation rate (mm/day)

Kc = crop coefficient (Given in Table 1)

Wa = wetted area, % (Assumed 100% of the total area)

Eu = emmission uniformity (approximately 1)

The irrigation period of the paddy is classified into three stages like Transplant or Direct sowing, Mid season and Harvesting and also their relative crop coefficient constants, Kc values [3] are shown in Table 2. Monthly average daily Pan Evaporation rate, PE values [4-6] are calculated and they are shown in figure 1. The calculated values of monthly average daily peak water requirement per acre using equation (1) are shown in figure 2.

Table 2. Irrigation periods of paddy

Growth Stages	Crop coefficient constant (Kc)
Transplant or direct sowing (1-60 days)	1.1
Mid season (61-120 days)	1.3
Last 30 days before harvest (121-150 days)	1.0

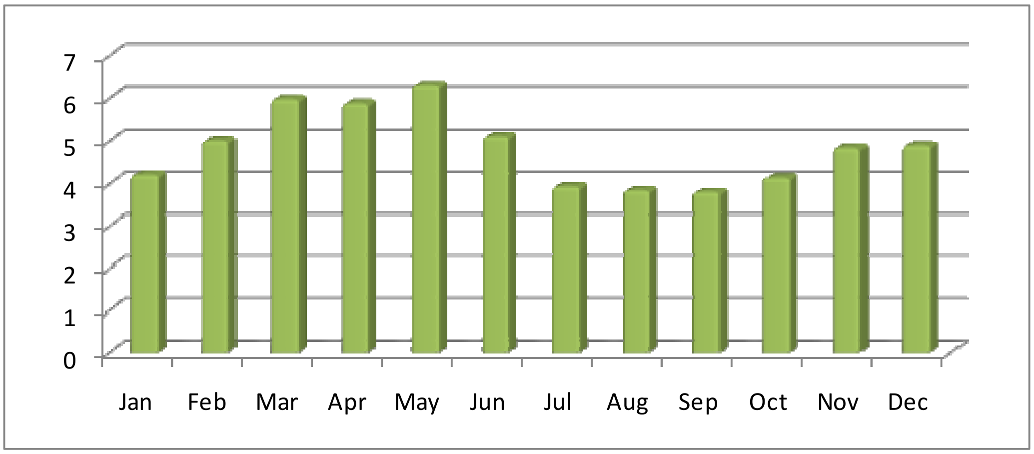

Fig.1 Monthly pan evaporation rate (mm/day)

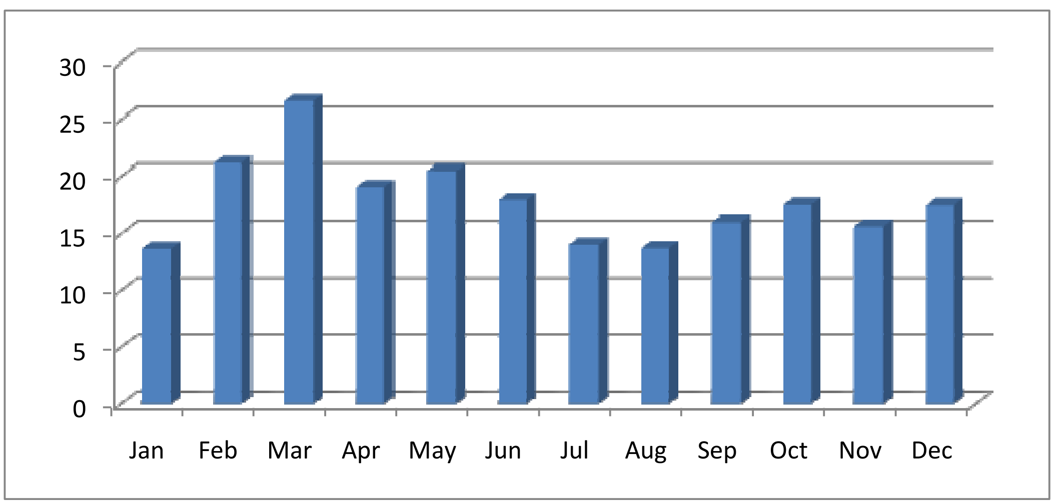

Fig.2 Monthly average daily peak water requirement (m3/day)

III. DETERMINATION OF THE HYDRAULIC ENERGY REQUIREMENT

The power output from the PV (Photovoltaic) array mainly depends upon the solar radiation on a particular location per day or total sun shine hours available and orientation of the panels with proper tilt angle. The Hydraulic energy required to lift the water from the ground depends upon the power output from the PV array. Solar radiation varies from month to month and one place to another, which is shown in Table 3. Data provided in the Table 3 is obtained at its optimal tilt angle which is equal to the latitude angle of the location considered [7-9]. The design of SAPV systems are generally based on the value of worst month radiation. This process can be taken into the account if water requirement is same throughout the year for irrigation of the land. But in this particular study, water requirement varies from month to month. The solar water pumping system is designed based on the ratio of the peak water requirement to solar radiation [1].

Table 3

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar radiation (MJ/m^2)	20.37	22.39	23.32	22.32	20.16	15.99	14.40	14.76	15.48	16.05	18.36	19.08

Table 4

S.No	Month	Water requirement (m^3/day)	Solar radiation (MJ/m^2)	Ratio
1	Jan	15.00	20.37	0.73
2	Feb	21.15	22.39	0.94
3	**Mar**	**26.60**	**23.32**	**1.14**
4	Apr	19.04	22.32	0.85
5	May	20.46	20.16	1.01
6	Jun	17.88	16.40	1.08
7	Jul	13.98	14.40	0.97
8	Aug	15.90	14.76	1.07
9	Sep	15.99	15.48	1.03
10	Oct	13.43	16.05	0.83
11	Nov	15.64	18.36	0.85
12	Dec	17.42	19.08	0.91

The highest value of the ratios shown in the Table 4 for which system hydraulic energy requirement is calculated [1] using the following equation (2).

$$E = \frac{\rho \times g \times H \times Wr}{3.6 \times 10^6} \quad (2)$$

Where, E = Hydraulic energy required (KWh/day)
ρ = density of water (1000kg/m^3)
g = gravitational acceleration (9.81 m/sec^2)
H = total hydraulic head (m)
Wr = volume of peak water requirement (m^3/day)

By putting all values, equation reduces as follows,

$$E = 0.002725 \text{ H Wr KWh/day} \quad (3)$$

IV. DETERMINATION OF SIZING OF THE PV ARRAY

From the Table 4, It is observed that the value of highest ratio is in March month and corresponding peak water requirement is 26.60 m^3/day. Total head of the system considered in this working area is nearly 45 m. Therefore, using the equation (3), total hydraulic energy requirement, E is equal to 3.26 KWh/day. Wattage of PV panel array at the assumed sunshine hours of 5.5 per day is 593 W (0.8 HP ≈ 1HP). The total wattage of PV panel array at the sub system efficiency of 0.4 and mismatch factor of 0.85 is nearly 1.75KW. In this paper, all the calculations are carried out for 1 acre. The figure.3 shows that the product catalogue of various models of submersible pumps from the company, Kirloskar [10]. From this catalogue, KU4-0709T model of 1.02 HP (≈ 1HP) is able to lift water from 44 m at the discharge of 60 liters per minute (lpm) which agrees with the above calculations.

WINNER -07 **PIPE SIZE: 32mm**

MODEL	kW	HP	Rated Current		DISCHARGE IN LPM					
					15	30	45	60	75	90
			1Ø	3Ø	TOTAL HEAD IN METRES					
KU4-0704T	0.37	0.50	3.5	1.4	28	25	23	20	15	8
KU4-0707T	0.55	0.75	4.5	1.9	50	44	40	34	26	16
KU4-0709T	0.75	1.02	5.8	2.5	60	57	52	44	33	22
KU4-0713T	1.10	1.50	7.9	2.9	88	82	74	64	48	29
KU4-0718T	1.50	2.00	11	4.5	120	113	103	88	66	40
KU4-0722T	1.90	2.50	13.8	-	132	127	120	107	90	86
KU4-0727T	2.20	3.00	15	6	179	170	155	132	100	60
KU4-0736T	3.00	4.00	-	8.5	239	227	208	176	133	83

Fig. 3 Data sheet of winner-07 pump set model by the Kirloskar company

V. LIFE-CYCLE COST ANALYSIS

Results from the life cycle cost analysis for proposed solar water pumping system:

- Capital PV cost, C_{pv} = Rs. 87,500/- (Assumed Rs.50/- per Wp)
- Operation and Maintenance cost,

$$C_{OM} = (2\% \text{ of the PV cost/year}) \times \left(\frac{1+i}{d-i}\right) \times \left(1-\left(\frac{1+i}{1+d}\right)^{N}\right)$$

$$= \text{Rs.}25{,}000/\text{-}$$

(Assuming an inflation rate *i* of 5%, an interest rate d of 10% and life time period, N of 20 years)

- Bench mark cost [12] to install a pump is Rs.160/- per peak watt (upto 5KW) = Rs.2,80,000/-
- Life cycle cost = C_{OM} + Benchmark cost = Rs.3,05,000/-

Results from life cycle cost analysis for existing grid water pumping system:

- Energy consumption for an acre in a day = 3×746 W×7 hr = 15.7 KWh
- Energy consumption for an acre/year = 15.7 × 300 ≈ 4.71MWh
- Energy consumption for an acre for a life time period of 20 years is nearly 94.2 MWh.
- Unit purchase cost by the power distribution company, APEPDCL is at the rate of Rs.5/KWh (for Low Tension side) [13].
- Life cycle cost = 115000 × 5 = Rs.4,71,000/-

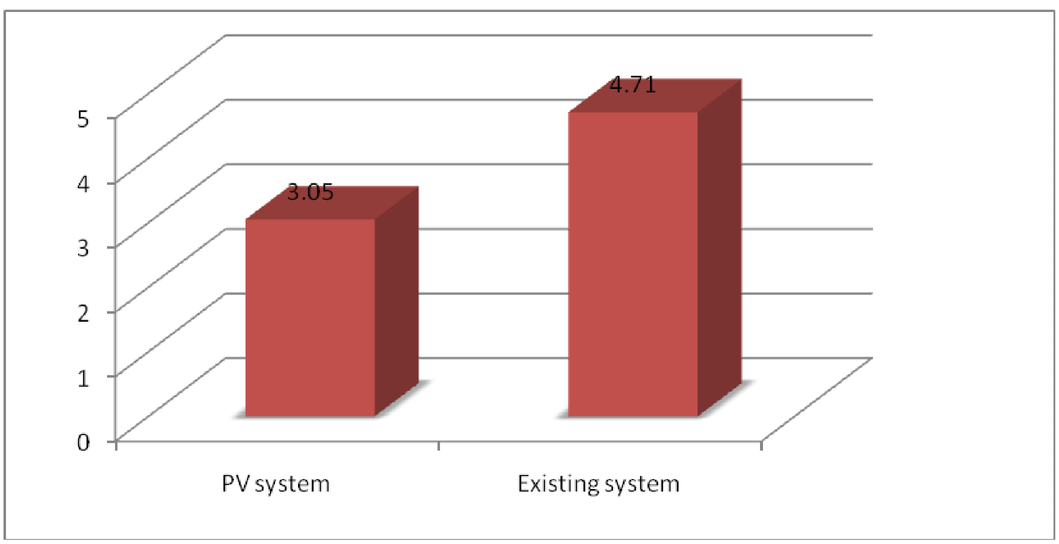

Fig.4 Life Cycle Cost comparison for 20 years (Rs. in Lakhs)

VI. RESULTS AND DISCUSSION

It is observed from the Table 4 that the designed value of pump set capacity to irrigate one acre of paddy field at the total head of 45 m is nearly 1 HP. Based on the designing procedure, this pump set can lift the water to wet the total land within 5.5 sun shine hours in all the months throughout the year. But, in the area of study it is observed that all twenty farmers from F1 to F20 have selected the pump sets with random values of machine capacities. And also these values are greatly deviated with the designed value i,e 1 HP. The total utilized pump set capacity is 300 HP for irrigating the total land of 107 acres. Therefore, the average HP utilization is around 3 HP per acre. As per the design calculations, 3 HP is not necessary for irrigating one acre of land. This situation is stating that 1 HP is sufficient to wet the paddy field of one acre within 5.5 hours at the total head level of 45 m. With this analysis it is clearly understood that nearly 2 HP/acre power is being drawn excessively by the framers in order to wet their land in short period of time. This causes, over burden the power distribution lines in terms of over current which leads to the high amount of power losses. Due to inappropriate usage of pump capacities it also causes the lower terminal voltages and may lead to damage of the equipment. From the fig.1, it can be determined that almost 1.02 HP of submersible pump can lift the water at the head of 44 m with discharge of 60 lpm. This is almost matches with the design procedure carried out in this paper.

VII. CONCLUSIONS

Based on the results the following conclusions and suggestions are made:

1. The proposed solar water pumping system can irrigate the one acre (0.4 ha) of paddy field by 1HP motor with daily water requirement of 26.6 m^3/day which is much less than the pump presently being used by the farmer.
2. The results of the study indicates that off grid or stand alone photovoltaic solar water pumping systems are more beneficial than the grid connected water pumping system as this reduces the burden on the system in terms of both peak load and energy requirement, thereby decreasing power losses.
3. From the results of life cycle cost analysis for 20 years, solar water pumping system is cost about Rs.3,05,000/- and grid connected system is about Rs.5,75,000/-.
4. As the significant difference in the cost is observed, solar water pumping system is more economical choice than the grid connected water pumping system.
5. Suggested road map for the Government for more qualitative benefits:

   a. Identify the crops/locations for which solar water pumping is suitable economically over its life cycle.
   b. A detailed study to be carried out to estimate the reduction in burden on the power as well as distribution losses for understanding its economic benefits from the Utility/State Government point of view. (So far most of the literature is focused on the benefits to the individual farmers)

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