Optimum Sizing of SPV Powered DC Irrigation Pumps based on Field Conditions

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Abstract—This paper presents a new method for estimating optimum HP rating of SPV powered DC irrigation pumps. In the proposed method hydraulic head, flow rate and efficiency are analytically obtained using field specific data to estimate optimum HP rating. Hydraulic head offered to pump is assessed by accurately analyzing static elevation and pipe network in the agricultural land. The flow rate is assessed by five hours operation of pump to discharge 70% of the crop water need per day. Efficiency of motor-pump assembly, corresponding to maximum head is identified experimentally. A motor-pump, as per the calculated optimum rating and powered by SPV source is experimentally tested in Energy Park, Basaveshwar Engineering College (Autonomous), Bagalkot, India. Tests are conducted for various discharge heads with varying solar intensities. Experimental and analytical results closely match, indicating the optimum selection of motor-pump. The proposed method helps in economic selection of irrigation pump and effective water management.

Index Terms— Head losses, Irrigation pump, Radiation, Solar Photovoltaic, Suction and Discharge head, Centrifugal pump.

1 Introduction

One of the promising applications of Solar PV (SPV) power, especially for India, where solar energy is abundantly available is irrigation. The key barrier to installation of solar PV water pumps is their high capital cost compared to the much lower capital cost of conventional irrigation pumps. High market prices of SPV devices, makes it necessary to correctly dimension photovoltaic solar power installations. Govt. of India proposed large number of SPV based irrigation pumps across the country. However, the successful implementation is yet to be seen. One of the probable reasons behind this is inaccurate sizing techniques for SPV powered DC water pumps [1].

Literatures show program assisted sizing methodologies for designing photovoltaic pumping system based on available potentials [2]. Concepts of reducing the SPV pump capacity with the care of local conditions are presented. Optimization procedures of photovoltaic water pumping systems, which have been the subject of numerous research papers, mainly deal with improvement of effectiveness of various system components, viz battery and inverter applications. It is evident that such sizing of SPV sources, whose price is still relatively high, doesn't yield optimum results. Outcome is increased investment that affects possible economic justification of such systems [3]. Thus, it necessitates to look for new sizing techniques for DC pumping systems powered by SPV.

In conventional irrigation system design motor ratings are decided based on the efficiency of pumping unit and hydraulic head. This optimization procedure is being followed since many years and suits well for conventional AC irrigation pumps, which work almost with constant efficiency and are fed from the grid. In case of solar powered units, system response keeps changing with solar radiation. This non linear behavior makes system design difficult. To conquer this, a methodology was developed to opt system capacity based on water requirement and head [4]. However, the parameters required for design were selected based on the pump manuals. This leads to uneconomic sizes of motors. In view of this, a new methodology is proposed to size SPV powered DC water pumping system based on site specific parameters. The methodology is validated by conducting performance analysis of PMDC motor coupled to a centrifugal pump at different solar intensities and at varying discharge head conditions. The research is carried under financial support from VGST, Department of IT, BT and S&T, Government of Karnataka, India.

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2 Methodology

Following sections present procedure to assess the field specific parameters.

2.1 Assessment of Head (H) Offered at the Field

As water flows through pipe, it experiences resistance due to which part of the energy gets lost. Losses developed on motor depend on elevation of water level to be lifted, bends, valves, friction and change in diameter of pipe.

A). Head offered to flow of water [6]*:*
It is the sum of static head and head losses. Total head offered is given by:

$$H = H_{static} \pm H_{Losses} \qquad (1)$$

Where, H is total head in meters, H_{Static} is total static head (Elevation) and H_{Losses} is total head losses.

B). Head loss due to friction:
Major loss of head is due to friction during the flow of water. This mainly depends on flow rate, pipe diameter, pipe length and roughness. This is assessed from Darcy-Weisbach method given by:

$$h_f = \frac{2 f l V^2}{g d} \qquad (2)$$

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Where, f is Coefficient of friction, a function of Reynold No., l is Length of pipe in m, V is Mean velocity of flow m/s, d is Diameter of pipe in m and g is acceleration due to gravity.

Velocity of fluid, *V* is calculated from flow rate of the pump at any value of radiation and head. This is given by:

$$V = \frac{Q}{A} \qquad (3)$$

Where, Q is Flow rate m^3/s and A is Area of pipe in m^2.

3). Head loss due to bends/valves/change in pipe area:

In case of long pipes these losses are quite small as compared to loss of energy due to friction and elevation. Hence, are neglected in conventional pump design procedure.However, in short pipes and small scale agriculture units these losses are comparable with friction losses. Minor losses are calculated by:

$$h_{Minor} = \frac{Kv^2}{2g} \qquad (4)$$

Where, K is Loss factor and is evaluated by :

$$K = \frac{F_T L_e}{D} \qquad (5)$$

F_T is friction factor and values of equivalent length in pipe diameter (L_e/D) of specific pipe fittings are presented in Table-1.

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Typical Values of L_e/D [7]

Pipe Fitting Description	L_e/D
90 Degree Standard Elbow	30
45 Degree Standard Elbow	16
90 Degree long Radius Elbow	20
90 Degree Street Elbow	50
45 Degree Street Elbow	26

2.2 Defining the Required Flow rate, Q_l:

In conventional system design, flow rate is selected based on required water output and time period for which motor is to be operated. However, water discharge from the SPV operated pump changes with radiation. Hence, required flow rate cannot be achieved.

This is attained by analyzing the variation of solar radiation in a typical day. Solar irradiation trend follows a parabolic nature and maximum power is available in mid-noon. It indicates approximately 70% of the water discharge is in the five hours of the day with constant and maximum flow rate.

Thus, flow rate in litres/min is calculated by (6):

$$Q_l = \frac{0.7 \times Q_{Total}}{300} \qquad (6)$$

Where, Q_l is Flow rate expected from the pump in lit/min and Q_{Total} is total water to be discharged from the pump/day.

2.3 Efficiency of Motor-Pump assembly, η%:

Electrical input to pump changes regularly with solar irradiation. This will force efficiency of the motor-pump assembly to change and head applied to pump will also affect the efficiency. Thus, efficiency of pump during the maximum irradiation (900 - 1000 W/m^2) is considered for analysis. Assessment of efficiency necessitates output of pump to be defined in Watts. Water discharge is represented as hydraulic power in watts by:

$$P_{Out} = \rho \times g \times Q \times H \qquad (7)$$

Efficiency of the motor-pump assembly is given by:

$$\eta = \frac{Hydraulic\ Power\ Output}{Electrical\ Power\ Input} \% \qquad (8)$$

2.4 Estimation of Power Rating for SPV DC Pump:

Electrical input to motor is provided by SPV panels. Substitution of head offered at location, discharge rate, and corresponding efficiency in power equation, input power required is assessed. Required power rating of the motor-pump assembly is given by :

$$P_{In} = \frac{\rho \times g \times H \times Q}{\eta} \qquad (9)$$

3 Experimental Setup

The proposed methodology is validated by conducting experiments on 1 HP SPV powered water pump. The set up consists of 6 PV panels (all in parallel), a DC PM motor coupled to centrifugal pump and pressure gauge is connected at the discharge terminal to monitor hydraulic pressure. Dynamic head on the pump is created through delivery valve. Water storage facility is created to pump water from 3 meters depth. The performance is noted at fixed tilt of panels. Solar radiation data from automatic weather station, installed in the Energy Park, is used. The performance of SPV pump and corresponding radiation data are tabulated. Test system is shown in Fig.1. Specifications of the test system are presented in Table.2. The Rotomag make DC water pump used for tests is shown in Fig.2.

Fig. 1. Test system at Energy Park, BEC, Bagalkot.

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TABLE 1
Specifications of Test System

SPV Array	
PV Array Capacity (W)	900 W
Power Rating of panel (W)	150 W
Open Circuit Voltage V_{oc} (V)	38 V
Short Circuit Current I_{sc} (A)	24 A
Voltage at Max Power (V)	31.3 V
Current at Max Power (A)	20.7 A
DC Motor-Pump Assembly (Rotomag)	
Model No	MBP 30
Capacity	1HP
Voltage	30V
Insulation	Class B
Pressure Gauge	4.2 Kg/cm^2

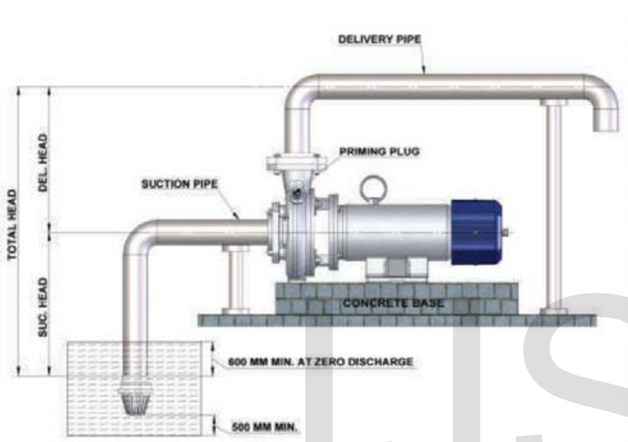

Fig. 2. DC water pump used for the test [9]

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4 Results and Discussions

Performance analysis of SPV powered DC motor coupled with centrifugal pump is carried out. Solar radiation, power output of SPV panels, water discharge and speed of motor are noted. Table.3 presents the performance of the system with head of 5 meters. In similar, performance of the system is studied at varying discharge head values of 5m, 6m, 7m, 8m, 9m, 10m and 12m. For each case, flow rate and efficiency are assessed at varying radiation.

Pump discharges the water from morning to evening without external interventions and operates with a good adaption for available intensity. It is observed that minimum radiation of 50 W/m^2 is required to pump the water. System discharges water at an average of 1.30 lakh liters/day. During maximum solar irradiation, it is observed that, discharge of water from pump is approximately 280 lit/min.

To represent annual solar radiation, the data for January, May and September months is used. Fig.3 presents average solar radiation in the said months. Solar intensity varies from 150 W/m^2 to maximum radiation and remains almost constant at certain value. It is observed from readings that effective maximum radiation in a day will be around five hours. During this period water pumping is effective. Variation of water flow rate from morning to evening is presented in Fig.4. It is observed that radiation and flow rate are maximum and almost constant in mid-hours of the day. Morning and evenings the discharge is reduced, however significant amount of pumping is carried. Fig.5 presents the comparison results of water discharged in different months. Water discharge in litres for every hour is assessed. The average water discharge versus time for various months is compared and analyzed. Comparison indicates that, approximately 70% of the water is discharged in the five hours in all the months. Thus, the proposed concept for assessment of flow rate given by (6) is validated.

TABLE 2
Performance of the system for 5 meters head

Radiation W/m^2	Pin (W)	Q (L/min)	Q (m3/Sec)	Pout (W)	Efficiency η%
325	241.31	25	0.000417	20.43	8.469308
350	259.87	29	0.000483	23.70	9.122655
375	278.43	35	0.000583	28.61	10.27609
400	297.00	41	0.000683	33.51	11.28535
425	315.56	67	0.001117	54.77	17.35710
450	334.12	74	0.001233	60.49	18.10550
475	352.68	83	0.001383	67.85	19.23870
500	380.62	88	0.001467	71.94	18.90049
525	399.65	94	0.001567	76.84	19.22777
550	418.68	99	0.001650	80.93	19.33005
575	437.71	102	0.001700	83.38	19.04990
600	456.75	106	0.001767	86.65	18.97209
625	475.78	110	0.001833	89.92	18.90049
650	494.81	112	0.001867	91.56	18.50398
675	513.84	116	0.001933	94.83	18.45503
700	546.00	120	0.002000	98.10	17.96703
725	565.50	124	0.002067	101.37	17.92573
750	585.00	125	0.002083	102.18	17.46795
775	604.50	128	0.002133	104.64	17.31017
800	624.00	131	0.002183	107.09	17.16226
825	643.50	136	0.002267	111.18	17.27739
850	663.00	141	0.002350	115.26	17.38575
875	682.50	145	0.002417	118.53	17.36813
900	735.75	151	0.002517	123.44	16.77778
925	756.18	156	0.002600	127.53	16.86486
950	776.62	160	0.002667	130.80	16.84211
975	797.06	164	0.002733	134.07	16.82051
1000	817.50	168	0.002800	137.34	16.80000

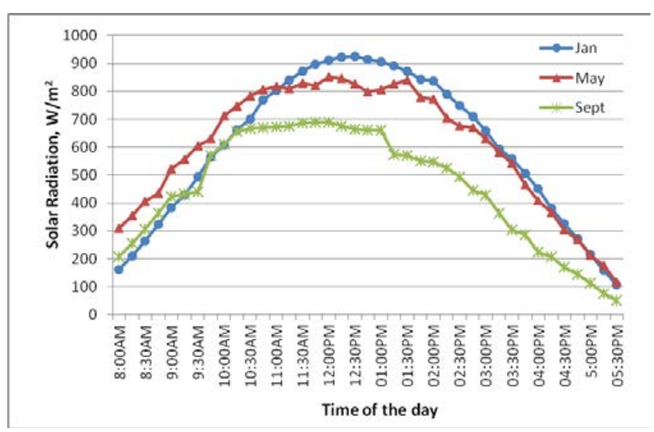

Fig. 3. Solar radiation data for different months

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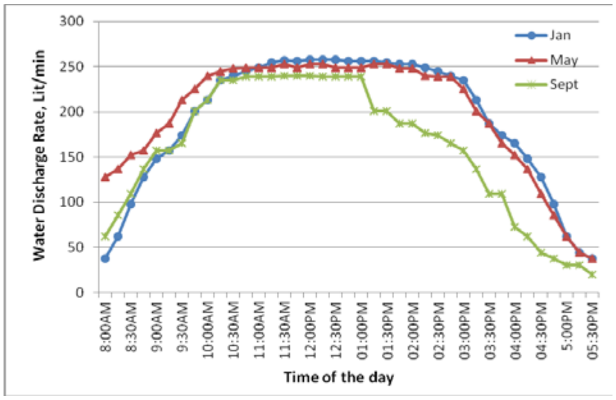

Fig. 4. Variation of water flow rate with time

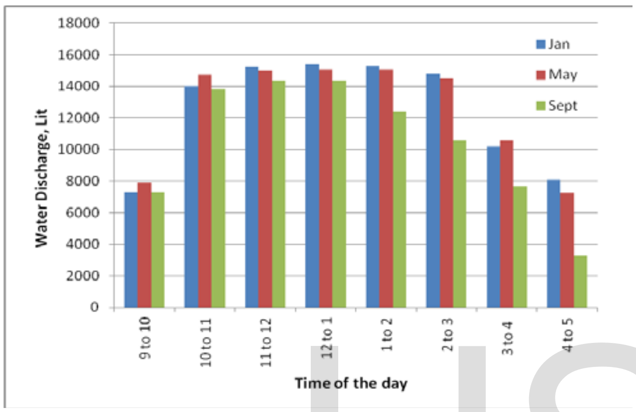

Fig. 5. Hourly water discharge in different months

Relation between water flow rate, solar radiation and corresponding efficiency of the pump at head of 5 meters on a typical day are presented in Fig.6. The graphs reveal that, efficiency is around 17% at 1000 w/m² radiation. With increase in radiation, efficiency is found to increase and then reduce gradually and remain almost constant. While, the water discharge increases with radiation. The key observation here is that, constant efficiency point is the optimum operating point at the corresponding head. In addition, the results for different heads are also obtained and analyzed.

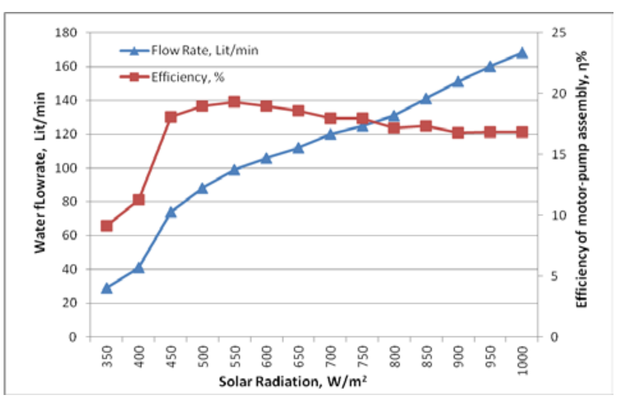

Fig. 6. Flow rate and Efficiency vs solar radiation for 5 meter head

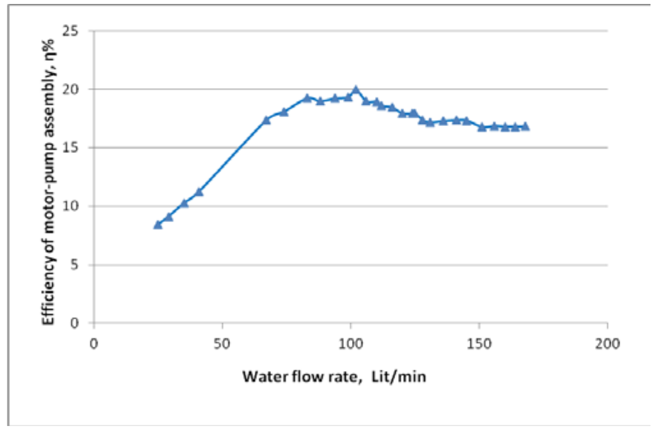

Fig. 7. Water flow rate vs Efficiency for 5 meter head

Efficiency of motor-pump varies with water flow rate at discharge terminals. However, these two parameters together depend on power input to motor and play a vital role in selecting the size for required application. Both parameters are expected to be linear with each other, but practical limitations pose the divergence. Variation of efficiency with flow rate is presented in Fig.7. Graph shows that, increased flow rate suffers from lower efficiency of motor pump assembly for given head. On the other hand, efficiency remains constant for given head condition at higher flow rates.

The effect of discharge head on efficiency has been studied to determine the optimum head for the system. Efficiency is obtained with reference to varying heads at 1000 W/m² radiation and is presented in Fig.8. At lower heads the efficiency is less; however the water discharge is adequate. With increase in head, efficiency increases till 7 meters head. This point is referred as best operating point for the pump. Further increase in head will lower the efficiency and water output reduces drastically.

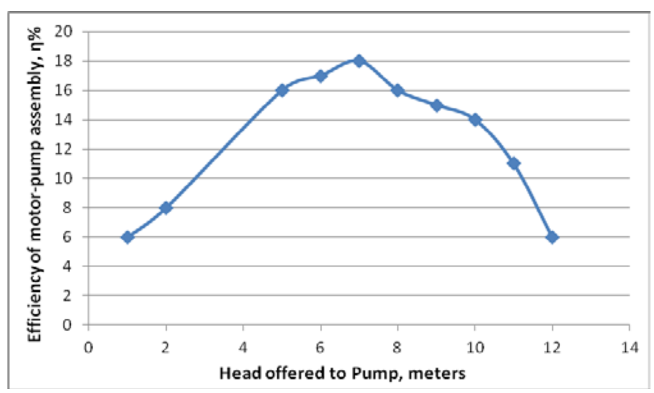

Fig. 8. Head offered vs Efficiency

The impact of hydraulic head on the water flow rate is analyzed by experiments. It is shown that for 1000 W/m² radiation and 5 meters head, discharge is at 170 lit/min. With increase in head, flow rate reduces steeply. At 14 meters head the discharge is zero. This characteristic is presented in Fig.9.

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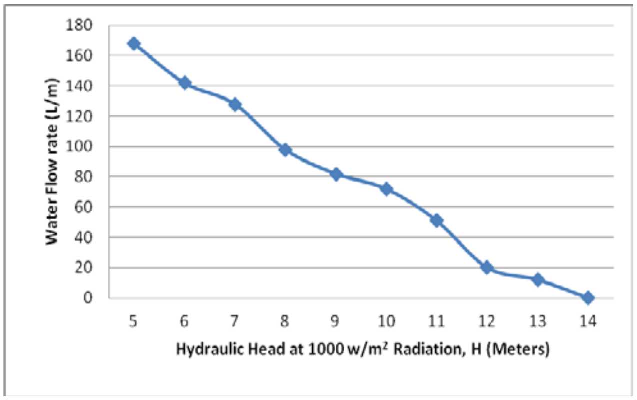

Fig. 9. Variation of flow rate with heads at 1000 w/m^2

Thus, with the available efficiency of pump and flow rate at any particular head, it is possible to obtain optimum rating of SPV DC pump for required quantity of water. The validated methodology is used for sizing motor-pump HP ratings for different conditions. Water requirements are selected from 50000 to 300000 liters per day for analysis. Flow rate is calculated for the period of 5 hours. Efficiency for all head values at 1000 W/m² radiation is selected from the test results. Further, Pump capacity required in HP is assessed using (1). Fig.10 presents the size of the DC water pump required for head value of 5m. Results presented are the optimum sizes SPV DC water pumps for corresponding head and water requirement. Fig.11 shows the comparison amongst the HP ratings for different heads.

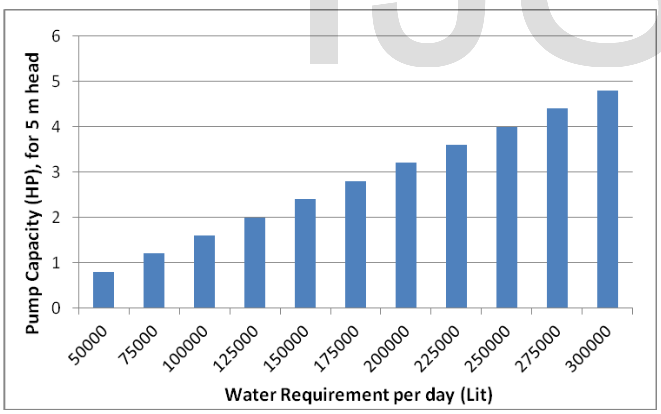

Fig. 10. Water requirement per day Vs HP rating, for 5 meter head

Comparison graph indicates the increased size of pump capacity with increase in water requirement and hydraulic head. It depicts that, increase in the HP values are in step manner. It is due to fact that, efficiency value for 1 HP pump is validated from experiments and for higher pumps same efficiency is considered. However, this may change slightly with practical conditions. But results presented will be optimum and economic. The proposed method can be effectively used for higher sized pumps by carrying out appropriate performance tests. Proper matching between the water requirement, motor-pump and SPV array will yield cost effective solutions for agriculture installations.

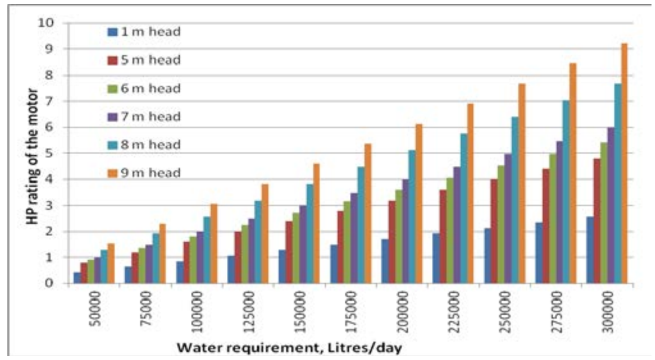

Fig. 11. Comparision of HP rating required for different heads

5 Conclusions

A new method to size SPV powered DC irrigation pump is presented in the paper. Procedure to assess the hydraulic head at agricultural land is described. New concept of selecting water flow rate based on the operating hours of SPV pump is presented. Water requirement, head offered and corresponding efficiency of motor-pump are considered for assessing the HP rating. Proposed methodology is validated by conducting performance tests on a 1 HP SPV powered DC pump. The proposed methodology is used assess HP ratings for water requirement of 50000 to 300000 liters of water per day and for heads varying from 1m to 12m. The results revealed that, proposed methodology is much suitable for small scale farmers, where water requirement can be assessed much nearer to the actual. It is shown that optimized selection of irrigation pumps can be effective in cost reduction as well as in water management.

References

[1] "Indian Power Supply Position 2010", CSTEP working paper series No. 1, 30.08.2010, Center for Study of Science, Technology and Policy, Bangalore-2010.
[2] Edward Chikuni, "Program-assisted sizing of a photovoltaic- powered water pumping system", Journal of Energy in Southern Africa, Vol 23 No 1, February 2012.
[3] A.A. Ghoneim, "Design optimization of photovoltaic powered water pumping systems", Applied Sciences Department, College of Technological Studies, Shuwaikh 70654, Kuwait, Energy Conversion and Management, 47 (2006) 1449–146.
[4] Basangouda F Ronad, Jangamshetti Suresh H., "A Novel method to determine optimum HP rating of Irrigation Pump Based on Water Requirement of Crop", IASTED International conference on Power and Energy, Asia PES-2013, April 10-12, 2013, Phuket Thailand. Paper Id 800-070.
[5] Zvonimir Glasnovic, Jure Margeta, "A model for optimum sizing of photovoltaic irrigation water pumping systems", Solar Energy 81 (2007) 904–916, www.elsevier.com/locate/solener
[6] R. K. Bansal, "Fluid mechanics and hydraulic machines" Laxmi publications ltd, 8th edition, 2002.
[7] Thomas Jenkins, "Designing Solar Water Pumping Systems for Livestock", Circular 670, Cooperative Extension Service, College of Agricultural, Consumer and Environmental Sciences, New Mexico State University.
[8] Mohanlal Kolhe, J.C.Joshi, D.P.Kothari, "Performance Analysis of a Directly Coupled Photovoltaic Water Pumping System", IEEE Transactions on Energy Conversion , Vol.19, No 3, September 2004.
[9] Solar Surface Pumps Instruction Manual, Rotomag Motors and Controls Pvt. Ltd. Gujrat.