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An Approach to Reduce the Size and Cost of PV Panel in Solar Water Pumping

Mrityunjaya Kappali
Research Scholar, Electrical & Electronics Engineering
National Institute of Technology Karnataka, Surathkal
Mangalore -575 025, INDIA
E-mail:mrkappali@rediffmail.com

Dr. Uday Kumar R. Y.
Professor, Electrical & Electronics Engineering
National Institute of Technology Karnataka, Surathkal
Mangalore -575 025, INDIA
E-mail: udaykumarry@yahoo.com

Abstract— **Of late Solar PV generation is finding prominence as a promising renewable source of energy. Water pumping is an important application of solar PV generation. However it suffers from the demerit that the initial cost is quite high which is mainly due to the high cost of PV panels. Present paper proposes a novel approach "Individual Floor Storage Method" for solar water lifting in multi-storied buildings. In this method water is pumped to the required optimum heights thus avoiding wastage of energy. Hence the energy required will be less for a particular amount of water to be lifted. This means there will be reduction in the size of photo voltaic panel and hence in the initial cost. In the present paper, solar pumping proposal without battery backup, is worked out for a house with two floors. It's found from the tests that with the proposed new approach, PV panel size and panel cost will decrease by 13% and 11.5% respectively.**

Keywords- Solar Water Lifting - Panel Size - Energy Saving.

I. INTRODUCTION

Supplying energy to remote places poses a challenge as the extension of traditional grid supply network is becoming costly. This added with the problems of fast depleting fossil fuels and ever escalating energy cost are triggering exploration of alternate sources of electricity. Among such sources, Solar Photo Voltaic (PV) source is finding lot of prominence due to its abundant availability.

Water pumping is an important application of solar PV power. However people are not opting for it in large number as the initial investment for solar pumping systems is high. This is evident from the fact that around the world only 60000 solar pumping systems are installed [1]. This number is just 5000 in India [2]. Hence it is necessary to devise the means of reducing the cost component. This can be attempted in two ways:

- Identifying less costly and more effective materials for solar PV panel.
- Improving the water lifting process itself making it more efficient. This means maximizing the extraction of the available energy and using it more efficiently. The work mentioned in this paper falls under the second category.

Section 2 of this paper deals with the basic aspects of solar pumping system. Section 3 narrates the present practice and proposes new strategy of water lifting in multistoried buildings. Section 4 presents the theoretical background. Section 5 discusses the application of new strategy for solar pumping system. Section 6 gives concluding remarks.

II. SOLAR WATER PUMPING

A. Basic Aspects

A solar pumping system can be with or without battery backup. A basic and simple configuration of direct coupled type consists of PV panel, motor-pump unit and storage tank (Fig.1). Typical advantage of the solar pumping system is that electric storage battery is not essential as compared to other solar PV applications [3]. Whenever the PV power is available, water is transferred to an over head tank which itself acts as a storage element. However the position of overhead tank is very critical.

B. Efficiency of Solar Pumping System

Average efficiency values [4] for different components of solar pumping system are shown in Table 1. From the table it's clear that overall efficiency, from solar radiation on panel to water output from pump is very less being of the order 2-3%. This poor efficiency leads to increase in the size of solar panel thereby increasing the initial cost. The initial investment can be kept low by: (i) utilizing all the possible power from the solar radiation and PV panel and (ii) utilizing this power more efficiently.

Useful output from a solar pumping system can be enhanced by:

- Trapping maximum radiation employing sun tracking.
- Controlling the operating point of solar PV panel employing Maximum Power Point Tracking (MPPT).
- Employing more efficient water lifting processes. The work mentioned in the present paper falls under this category.

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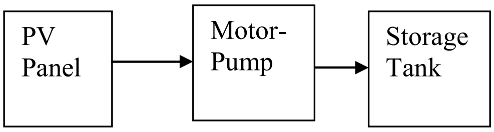

Fig.1 Basic Solar Pumping System

TABLE 1: SOLAR PUMPING SYSTEM EFFICIENCY

Component	% Efficiency
PV array	11
Maximum Power Point Tracking	94
DC Motor	55
Motor-Pump	45

III. WATER LIFTING IN MULTISTORIED BUILDINGS

A. Present Practice

Presently, in multistoried buildings, a single overhead tank is placed above the topmost floor. All the water is lifted up to that height and then brought down to lower floors (Fig.2). This method can be called as "Top Floor Storage Method (TFSM)". Here, even the water required at lower heights is unnecessarily lifted to higher levels. For example, for a two-storied building (ground + first floor) overhead tank is placed on the top of the first floor at a height of approximately 7m. This position of the tank is alright for the first floor water requirement. But, for the ground floor, though water is required at just 4m height, it is lifted up to 7m and then brought down. Such a lifting of water to unnecessary large heights means more energy consumption, which is wastage. This opens up an opportunity for energy conservation.

B. New Strategy

The new strategy [5] proposes that instead of one single large overhead tank on topmost floor, small tanks at each floor height are to be employed supplying water to corresponding floor (Fig.3). Independent pipe line is laid from pump to each floor tank through a multi output valve. Water is pumped to each floor tank independently using the valve. This strategy is termed as "Individual Floor Storage Method (IFSM)". Since the water is pumped to the required optimum heights only, it avoids wastage of energy.

IV. THEORETICAL BACKGROUND

Consider lifting of water in a multi storied building with the following features:

- Water required per floor per day = m L (= m kg)
- Number of floors = n
- Height of each floor = h m (assuming uniform floor height)
- Water is available in a sump at ground level of the building and suction head (Hs) = 0.

We will determine the theoretical energy required in each case i.e. with TFSM and IFSM. We know from the fundamentals of physics that the work done or energy spent (W) in lifting a mass of m kg through a height of h m is given by:

$$W = mgh \text{ J} \quad (1)$$

where g = acceleration due to gravity = 9.81 m/s^2. To make the mathematical treatment simple, we consider the system to be ideal. Hence only static head is taken in to account and the pipe friction head is assumed to be negligible.

A. TFSM

Supplying water for this building with TFSM means lifting nm L water/day through a height of nh m. Using (1), energy required per day (E_{tf}) for TFSM is given by,

$$E_{tf} = (nm)\, g\, (nh) = n^2 mgh \text{ J} \quad (2)$$

B. IFSM

Supplying water for this building with IFSM means lifting daily m L water through a height of h m for first floor, through 2h m for second floor, etc. up to through nh m for the topmost i.e., n^{th} floor. Total work done is the sum of the individual work done for each floor. Using (1), Energy required per day (E_{if}) for IFSM is given by,

$$Eif = mgh + mg(2h) + \ldots + mg(nh) \quad (3)$$

$$= mgh\, n(n+1)/2 \text{ J} \quad (4)$$

C. Saving in energy

It's clear from (2) & (4) that the energy required is less with IFSM compared to TFSM. Hence IFSM leads to saving in energy. We get,

$$E_{if}/E_{tf} = (n+1)/2n \quad (5)$$

$$\begin{aligned} \text{Saving in energy} &= E_{tf} - E_{if} \\ &= n^2mgh - [n(n+1)/2]\, mgh \\ &= [n(n-1)/2]\, mgh \quad (6) \\ &= [(n-1)/2n]\, (n^2 mgh) \\ &= [(n-1)/2n]\, E_{tf} \quad (7) \end{aligned}$$

From the above analysis we find that theoretically, the energy saving depends on: i) the number of floors ii) the magnitude of water lifted. The analysis can be extended to the case of non uniform floor heights also by substituting the corresponding floor heights in the relevant equations. Suction head, wherever present and considerable, can be accounted for by adding it to delivery head (Hd) and thus getting total head (H) as H = Hs + Hd.

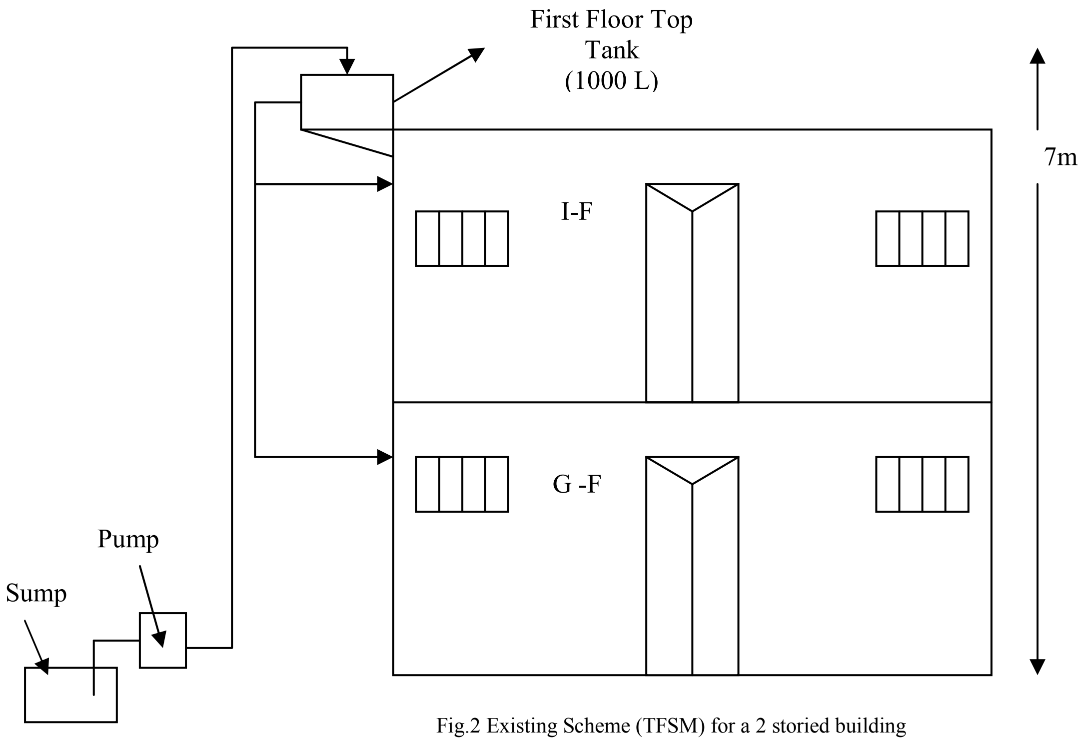

Fig.2 Existing Scheme (TFSM) for a 2 storied building

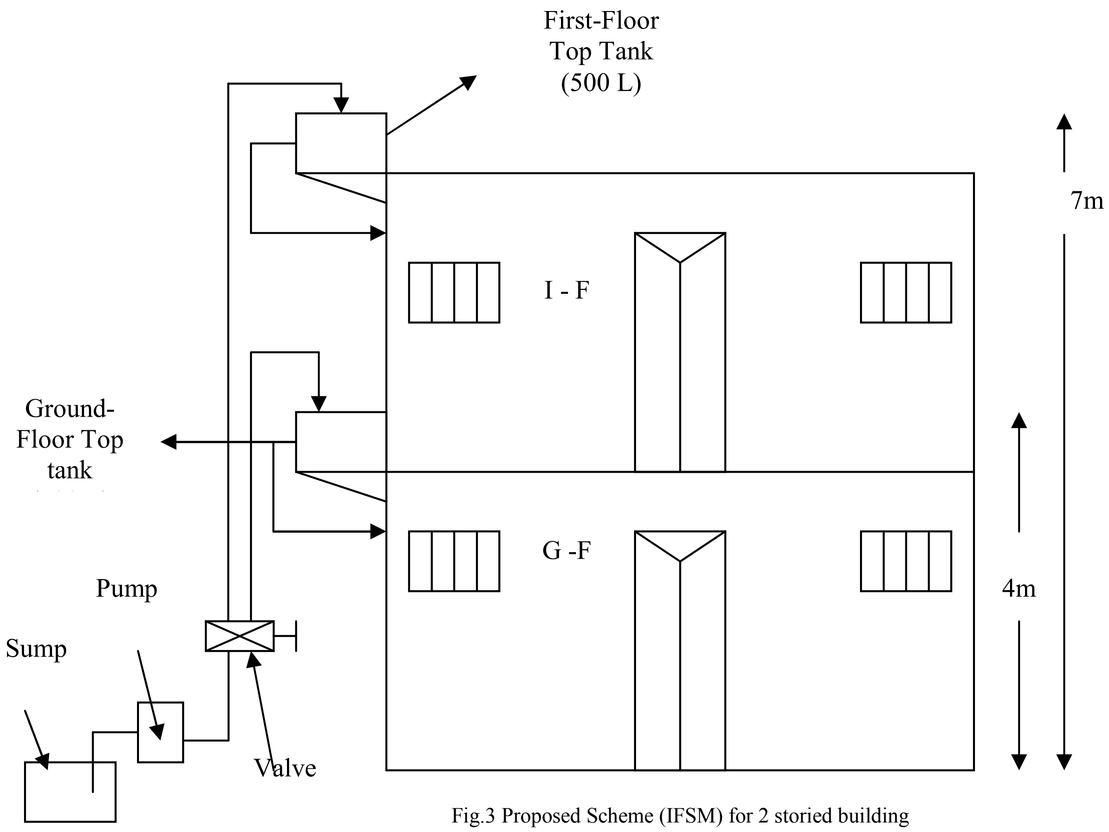

Fig.3 Proposed Scheme (IFSM) for 2 storied building

V. APPLICATION OF IFSM FOR SOLAR PUMPING

Presently solar pumping in multistoried buildings is done using TFSM. But as discussed in section IV, energy can be saved by employing IFSM. This is explained by taking an example of providing solar pumping system to a 2-floored (ground + first floor) house. Proposal is made with both the methods TFSM and IFSM, showing the feasibility and advantages of employing IFSM. The house considered has the following features:

- Location: Dharwad, Karnataka, India.
- Water requirement: 250 L/day for each floor (total: 500 L/day).
- Overhead tank size is to be such as to give one day back-up.
- There is a sump of 1.4m depth. Water is collected in this sump from the municipal supply and then lifted up to overhead tank.
- Solar pumping system is of direct coupled type i.e., there is no storage battery.
- MPPT is assumed to be incorporated. This means maximum power from the PV panel is available continuously.

A. TFSM based Proposal

The set-up will be as shown in Fig 2. The TFSM based proposal is detailed below.

- OH tank is placed on first floor top. It's a 1000 L poly vinyl chloride (PVC) tank providing one day backup.
- Water is drawn from the sump (suction head Hs=1.4m) and pumped to overhead tank (Hd=7m) and stored. From there it's supplied to ground floor and first floor.
- 70-100W, 12V dc, 9m head, surface mounted dc solar pump, which is widely employed in the local solar applications, is selected. The flow variation as a function of power for different heads for this pump is given in Fig 4. Minimum power to start pumping and the corresponding discharge rates are given in Table 2.

TABLE2: FLOW RATE OF PUMP (HS=1.4M)

Hd (m)	Minimum Power to start pumping (W)	Flow Rate Q (L/min)
4 (ground floor tank level)	60	3.5
7 (first floor tank level)	75	3.4

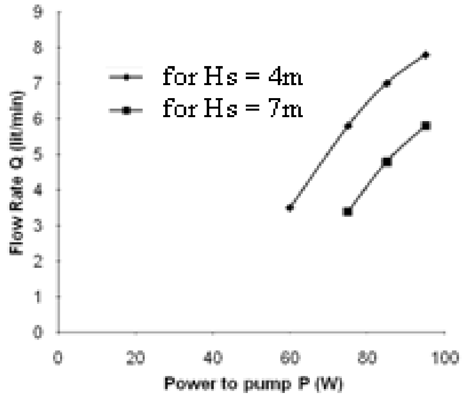

Fig 4 Flow Vs Pump Pows

- **PV Panel Sizing:**
  - Quantity of water lifted is given by,
    Water lifted = Flow rate x Duration of pumping (8)
  - Let the pump be operated with the minimum power i.e. 75 W. For this case, Required duration of pumping = Water lifted/ Flow rate = 500/3.4 = 147 min ≈ 2.5 h.
  - Hence the pump is to be run with minimum 75 W power for at least 2.5 h so that the water lifted is more than or equal to required quantity per day i.e. 500 L.
  - This means the solar panel has to yield ≥75 W for at least 2.5 h. However, to compensate for the highly variable nature of solar insolation, we include a factor of safety of 50%. Hence the required duration of minimum power availability is taken as 50% more i.e. 1.5 x 2.5 = 3.75 h. We select that minimum size of solar panel for which ≥75 W is available for at least 3.75 h. This is found to be 155Wp. Hence 155Wp, 12V panel is proposed.
  - For this panel, peak power availability at different times of the day is plotted in Fig 5.
- Consolidated proposal for TFSM is given in Table 3.

TABLE 3: MAJOR COMPONENTS (TFSM PROPOSAL)

Item	Features
PV panel size	155 Wp, 12V.
Overhead tank	1000 L PVC on first floor top.
Pump	70-100 W, 12V dc, totalhead : 9m, surface mounted

B. *IFSM based Proposal*

The set-up will be as shown in Fig 3. The IFSM based proposal is detailed below.

- Provide two 500 L PVC overhead tanks, one on ground floor top and the other on first floor top. The tank size is so selected as to provide one day backup.
- Pipe line is to be laid from pump to each tank separately through 2-way valve.
- The same pump proposed for TFSM is selected here also. Minimum power to start pumping and the discharge rates at different heads for this pump are given in Table 2.
- Water is drawn from the sump (Hs=1.4m) and pumped to first floor tank (Hd = 7m) when available power is ≥75W and to ground floor tank (Hd = 4m) when the available power is ≥60 W and <75 W using 2-way valve. This is done so as to account for the minimum power requirement to start pumping for different floor levels.
- **PV Panel Sizing:**
  - Using (8), we find that:
    Required duration of pumping for ground floor (considering minimum power of 60W)
    = Water lifted/ Flow rate
    = 250/3.5 = 71.5 min ≈ 1.25 h
    Required duration of pumping for first floor (considering minimum power of 75W)
    = Water lifted/ Flow rate
    = 250/3.4 = 73.5 min ≈ 1.25 h
  - Hence the pump is to be run with ≥75 W power for at least 1.25 h and with ≥60W and <75 W power for at least 1.25 h so that the water lifted is more than or equal to expected quantity per day i.e. 250 L for each floor.
  - This means the solar panel has to yield ≥75 W for at least 1.25 h and 60 to 75 W for at least 1.25 h. However as done earlier, to compensate for the highly variable nature of solar insolation, we include a factor of safety of 50%. Hence the required duration of minimum power availability is taken as 50% more i.e. 1.5 x 1.25 = 1.875 h. We select that minimum size of solar panel for which ≥75 W is available for at least 1.875 h and 60 to 75 W is available for at least 1.875 h. This is found to be 135Wp. Hence 135Wp, 12V panel is proposed.
  - For this panel, peak power availability at different times of the day is shown in Fig 5.
- Consolidated proposal for IFSM is given in Table 4.

TABLE 4: MAJOR COMPONENTS (IFSM PROPOSAL)

Item	Features
PV panel size	135 Wp, 12V.
Overhead tank	Two 500 L PVC tanks (one for each floor)
Pump	70-100 W, 12V dc, total Head : 9m, surface mounted
Pipe line	Independent pipeline with 2-way valve

TABLE 5: DURATION OF PUMPING & WATER LIFTED

Method	TFSM	IFSM	
Panel Size	155 Wp	135 Wp	
Hd (m)	7 (ground floor tank)	4 (ground floor tank)	7 (first floor tank)
Q (L/min)	3.4	3.5	3.4
Pumping Duration (h)	2.5	1.25	1.25
Water Lifted (L)	**510**	262.5	255
		Total: **517.5**	

C. *Cost and Saving Calculations*

A comparative idea of different aspects for both the methods is given in Table 5. The cost calculations are done with the following assumptions:

- Cost of PV panel is $ 5.55/Wp
- There is provision like landing space of staircase to keep the ground floor top tank. Hence no additional civil construction is required for this purpose.
- Cost of one 1000 L PVC tank is the same as the cost of two 500 L PVC tanks. Tank cost is taken as $ 0.06/L.
- Additional cost of $ 11.5 is incurred for IFSM towards 2-way valve and additional pipeline to be provided from pump to ground floor tank.

The details are given in Table 6. There is downsizing of PV panel and reduction in cost for IFSM as compared to TFSM.
Reduction in size of PV panel =155-135 = 20 Wp

% Reduction in panel size = (155-135) 100/155= **13%**
Monetary Saving = 155x5.55 – 135x5.55 - 11.5
= 860.25 - 749.25 - 11.5 = $ 99.5

% Monetary saving on panels = (99.5x100)/860.25 = 11.5**%**

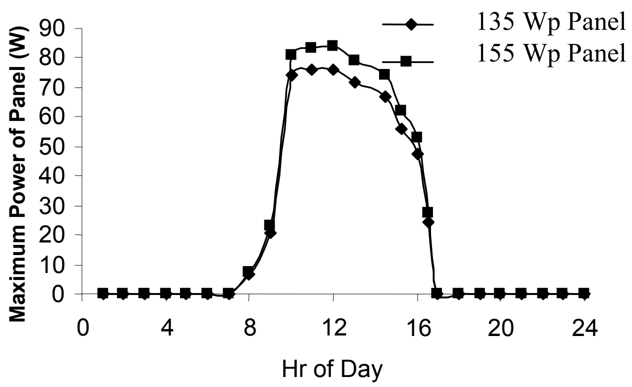

Fig 5 Maximum Power Vs Time

TABLE 6: COST CALCULATIONS OF TFSM AND IFSM FOR SOLAR PUMPING

Method	TFSM	IFSM
Cost of panel ($) @ $ 5.55/Wp	155 x 5.55 =860.25	135 x 5.55 = 749.25
Pump Cost ($)	111	111
Tank Cost ($) @ $ 0.06/L	60	30+30 = 60
Normal Plumbing and others ($)	23	23
Additional Expenditure ($)	- - -	11.5 (additional plumbing & 2 way valve)
Total cost ($)	1054.25	954.75
Reduction in panel size = 13%		
Monetary Saving on panels = 11.5**%**		

Existing practice in solar water pumping for multi-storied buildings employs top floor storage method. Here considerable amount of water is pumped to unnecessary heights resulting in energy wastage. Hence larger rating PV panel is required which increases the initial investment. Present paper has proposed a novel strategy “Individual Floor Storage Method”. Here water is pumped to required optimum heights and hence energy is saved. PV panel gets down-sized decreasing the initial cost, which has been a major impediment in the acceptance of solar pumping systems.

For the solar pumping for a 2-floored house considered as an example, the test results show that with the proposed new method there is 13% reduction in PV panel size and 11.5% drop in the panel cost. This benefit will be more pronounced if implemented for multistoried buildings with large water consumption like hospitals, hostels, flat complexes etc. Hence in the present day scenario of mushrooming multi storied buildings, individual floor storage method is more appropriate compared to the existing top floor storage method for solar pumping applications.

It is also to be noted that there are some challenges with individual floor storage method which we need to tackle like automating the process of directing water to different floors and constructional provisions to position overhead tank at each floor.

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