Canal Top Solar Energy Harvesting using Reflector

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Abstract

Solar energy is one of the most abundant sources of renewable energy for the future. This solar energy can be extracted by PV system. Many methods for PV installation are carried out, such as roof top PV system, dam top PV system; floating PV, canal top PV system etc. In canal top system, PV panels are placed above the water canal which saves installation area and reduces evaporation loss. The performance of any PV system depends mainly on the light intensity, so by a concentrating PV system power output can be increased. The usage of concentrated PV system can bring down the investment cost per kWh. In this paper canal top PV system with reflectors in the inter array spacing are studied. The expected advantage of such a system is that the evaporation loss can be further reduced and additional cooling system may not be required. To get uniform availability of light and to avoid shading on the panels, tilt angle of the panel, inter array spacing and orientation of the reflectors are calculated optimally.

Keywords- Photovoltaic cells, Concentrating PV (CPV), Photovoltaic, Solar panel cooling, Hydraulic canal, Solar panel temperature

I. INTRODUCTION

Recently, renewable energy systems have undergone rapid developments around the world, and certain renewable energy industries, such as solar and wind, have attained annual growth rates of 20% or more [1]. Renewable energy is an important alternative source of energy that promotes sustainable development in energy sector. Solar photovoltaic (PV) technology is the most common renewable energy option for clean energy generation. Since the power generation from solar is very expensive, it is not very popularly used. To overcome this problem there are number of methods, which includes the concentration of solar radiation and electrical thermal co-generation. The electrical current produced in a solar cell is, in principle, proportional to the solar radiation intensity on the surface of the cell. Solar concentrators are used to increase the irradiance on the cell surface, and thus the electricity production. So concentrating systems has the potential for reduced cost of solar electricity due to a smaller cell area. When a solar cell is exposed to concentrated sunlight, its temperature increases and this reduces the cell efficiency and this in turn reduces power output. In this way few benefits of concentrating the sunlight may be lost. The simple, straight forward method to this problem is to cool the solar cells. The cooling can be passive by means of cooling fins, or active by means of a cooling medium. If water is used as the coolant, the thermal energy can be utilized for heating applications.

An introduction to concentrating photovoltaic system, its history, properties of electromagnetic radiation and applications of CPV are discussed in [2]. The main factors affecting the solar PV performance are solar irradiation, temperature, orientation of the panel, shading [3] [4]. Filipa Reis [5] discussed about development of photovoltaic systems with concentration, in which CPV configuration and comparison of normal and concentrated PV system are explained. The main design considerations of the CPV are thermodynamic and electrical considerations, optical considerations and economic considerations [6]. Concentrated PV systems are classified into low concentration, medium concentration and high concentration [7]. In [8], they discussed about different types of concentrating technologies in PV system. Mehrdad Khamooshi et al. [9] give a review of Solar Photovoltaic Concentrators and mention about the advantages of CPV over normal PV system. Taylor Briglio et al. [10] discussed a feasibility analysis of installing solar photovoltaic panels over California water canals.

In this paper a canal top solar system is studied with plane reflectors for the concentration of the sunlight. The main parameters affecting the PV performance is irradiation, temperature and shading which is optimized. Additional cooling is not required due to the presence of water in the canal which condenses to give a cooling effect. The evaporation loss of water may further reduce and an additional solar radiation falls on the panel by the use of reflector.

II. HYDRAULIC BENEFITS OF THE CANAL

The trapezoidal section is the most common and practical canal cross section, which is used to convey water for irrigation, industrial and domestic uses. In order to calculate the loss of water due to evaporation, the U.S. geological Survey (USGS) offers an estimation of the amount of evaporated water per year [11].

$$E = 4.57T + 43.3 \qquad ----(1)$$

Where E – Evaporation (cm/year)

T – Yearly average temperature (°C)

A vital hydraulic advantage obtained by the canal top system is the absence of evaporation due to direct radiation. By this method surrounding areas may achieve significant agricultural development [11].

III. CANAL TOP PV SYSTEM WITH REFLECTOR

The efficiency of a solar cell depends on irradiance and cell temperature. Ideal solar cell efficiency increases logarithmically with the irradiance, but in practice the series resistance in the cell limits the efficiency. The increase of cell temperature with accumulated irradiance is probably the biggest disadvantage with booster reflectors for PV modules and in a very real application this needs to be treated seriously. Several different techniques for cooling the modules are available. In this paper a combination of canal top PV system and concentrated PV system with plane reflector are studied. Here plane reflectors are placed on the canal top PV system to improve the performance of the system. Temperature of the panel is not increased due to the presence of the water in the canal which gets condensed. Placing reflector is economical in case of canal top projects because costs of the supporting structures are very high compare to the reflector cost. The expected advantages of the proposed system are

1) Solar radiation falling on the panel may be increased.
2) Efficiency of the canal top PV system may be enhanced.
3) Evaporation loss of the water in the canal may be reduced.
4) Strength of the supporting structure may also be increased.

Based on the direction of canal water flow there are two cases for the proposed system.

– Case 1: Canal in the East-West direction.
– Case 2: Canal in the North-South direction.

A. Canal in the East – West Direction

In this case water flow through the canal is in the East- West direction. Panel is placed on the top of the canal in a south facing manner. In this case plane reflectors are placed on both sides of the PV panel as shown in the Fig. 1.

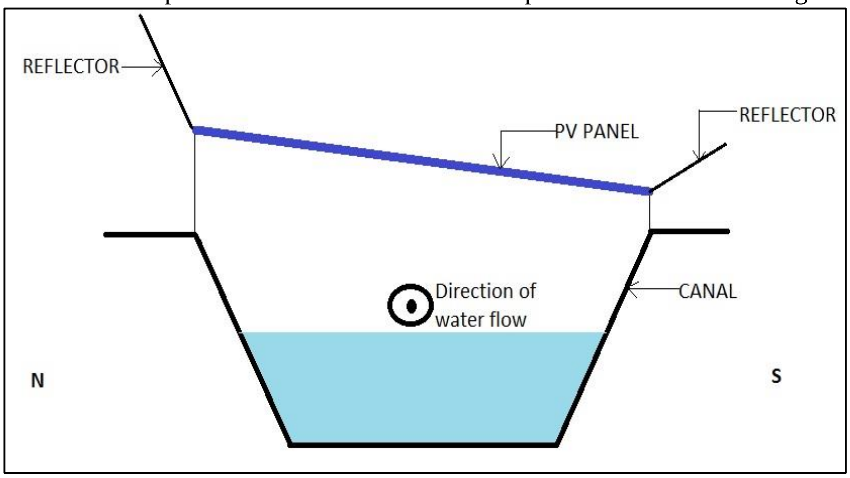

Fig. 1: Canal top project with reflector on sides

B. Canal in the North – South Direction

In this case in order to place the PV panel in the south direction and to limit the slope, inter array spacing is provided between each string. The proper design of this inter array spacing is necessary to avoid the shading conditions. In the proposed system, the plane reflector is placed in the inter array spacing. So intensity of solar radiation falling on the PV panel may be increased there by the efficiency of the entire system may also increase. Fig. 2 shows this system.

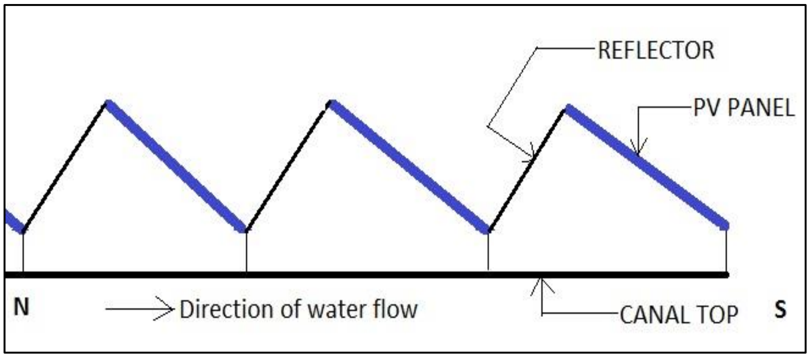

Fig. 2: Canal top project with reflector in the inter array spacing

IV. METHODOLOGY

A. Tilted Array Spacing

The main constraint coming up with solar array is shading. Most locations for solar projects tend to induce around 5 to 6 net sun-hours per day, thus something that obstructs that sunlight must be avoided in any respect. Shading only on one corner of a module will cut production in half, thus avoiding shade on the array is very important. This can be a main problem on ground mounts and a few flat roof mounts, wherever rows of solar panels need to be optimally spaced to best use the obtainable space. With restricted solar resource and steep penalties for failure, properly deciding correct shade spacing may be a crucial calculation in solar system design.

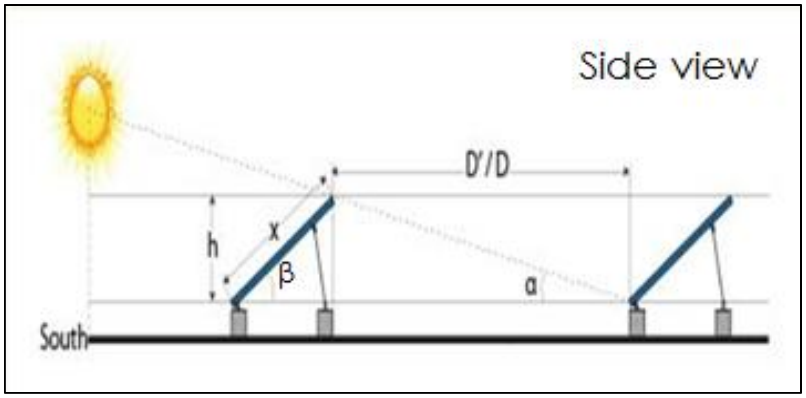

Fig. 3: Inter array spacing calculation-Side view

In order to calculate shadow spacing, first find the suns position within the sky on the winter solstice. December 21st the sun will be low within the sky which provides maximum shading. To find the suns position minimum solar altitude angle α is required, that is the minimum angle the sun makes with the ground in the shade-free solar window (Fig. 3). For a 4 hour solar window, suns altitude angle at 10 AM or 2 PM on December 21st is needed. After notice this angle, it is possible to get the suns azimuth angle ψ, it shows how far away true south the suns position is (Fig. 4). By using these two angles the minimum allowable row spacing can be calculated [12].

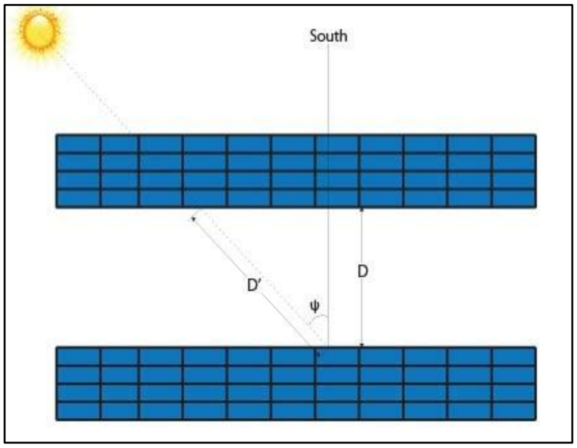

Fig. 4: Inter array spacing calculation-Top view

After determining the solar altitude and azimuth angles, the calculations to see row spacing is done. For many ground and roof mounted systems wherever row spacing is a concern, the height (h) of the obstruction may be directly obtained from the size of the solar panel and also by the array tilt [12]. Alternately, it may be measured because the difference in height between the bottom/leading edge of one row and the maximum height of the subsequent row that is south of it, or an immediate measure of any obstruction you want the array to avoid (Fig. 3). Using this height, the maximum shadow distance can be obtained by using simple mathematics. The equation is:

$$D' = \frac{h}{\tan\alpha} \qquad ----(2)$$

From here, only one additional calculation provides the minimum inter-row spacing required to avoid shade inside your solar window. This is often referred to as the solar azimuth Correction (Fig. 4). Using the morning sun position, the equation is:

$$D = D' * \cos(180 - \varphi) \text{ during morning} \qquad ----(3)$$
$$D = D' * \cos(\varphi - 180) \text{ during afternoon} \qquad ----(4)$$

Where
α - solar altitude angle
ψ - Solar azimuth angle
h - Height of obstruction
x - Tilted module length
β - Tilt angle
D - Minimum array row spacing
D'- Maximum shadow length

V. MODEL OF THE PROPOSED SYSTEM AND CALCULATION

In order to find the optimum inter array spacing and orientation of the reflector a small PV panel is considered. The model for the proposed system is shown in the Fig. 5. Table 1 gives the specification of the PV panel used.

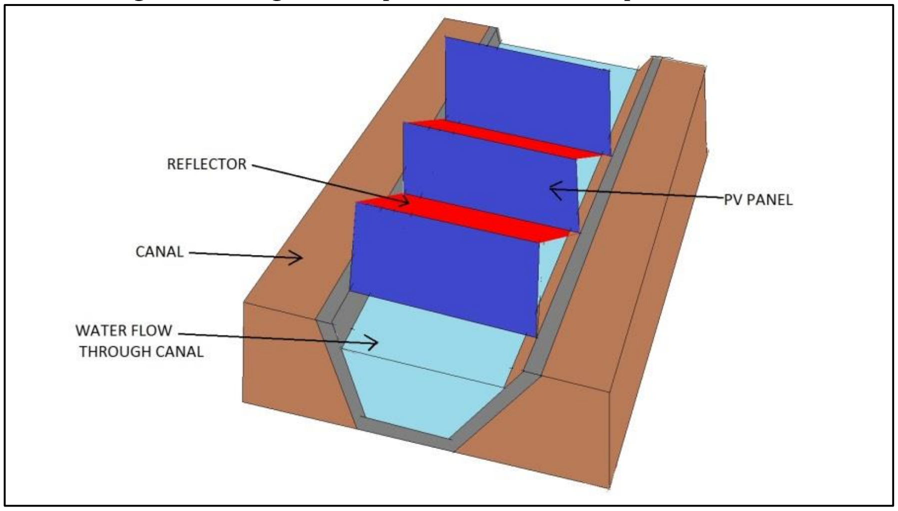

Fig. 5: Canal top project with reflector in the inter array spacing

Table 1: Specification of the panel and sun angles

Panel length	*0.66 m*
Panel width	*0.46 m*
Type	*Poly crystalline*
Power rating	*40 Wp*
Voltage at MP	*17.4 V*
Current at MP	*2.30 A*

A. Calculation of Tilted Array Spacing

Solar azimuth angle and solar elevation angles are obtained from the Sun path chart generated using the PV Syst software [13] shown in Fig. 6.

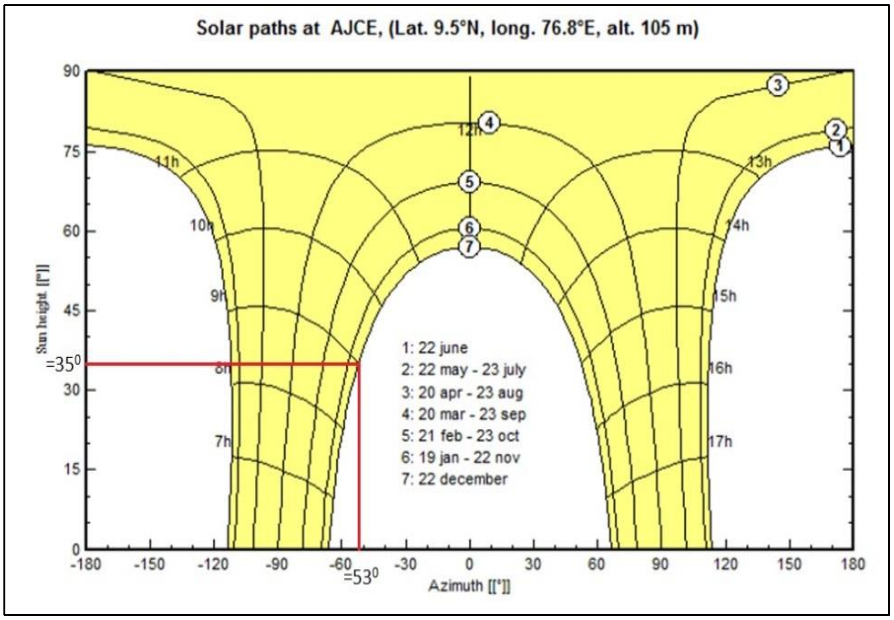

Fig. 6: Sun path chart generated using PV Syst software

$h = \sin\beta * w = \sin 10 * 0.66 = 0.1146\ m$

$D' = \frac{h}{\tan\alpha} = 0.1637\ m$

$D = D' * \cos(180 - \varphi) = -0.0985\ m$

The effect of shadowing is studied using the PV Syst software. Same dimensions of the PV panel are used and it is obtained that the beam linear loss is only 0.4% with the calculated inters array spacing as shown in Fig. 7.

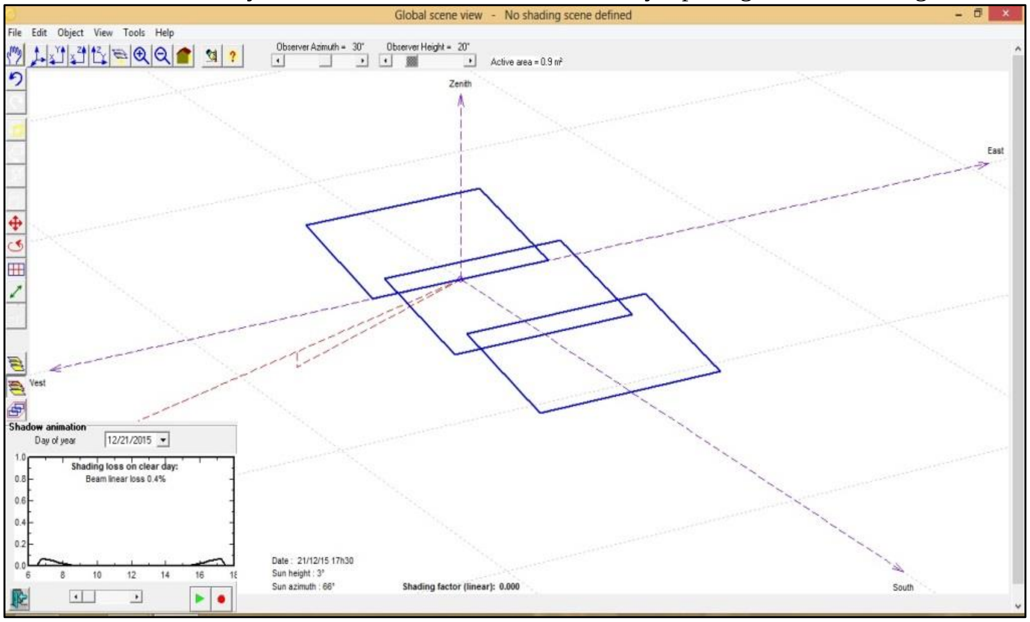

Fig. 7: Shadow calculation using PV Syst software

In the proposed system, reflectors are placed in the inter array spacing. By this, solar radiation falling on the panel can be increased and temperature rise is minimized due to the presence of water in the canal which may condense.

B. Calculation of Reflector Orientation

To optimize the solar radiation falling on the reflector which is placed on the inter array spacing; the orientation of the reflector is to be done properly. For that purpose an expression for x, which is the maximum distance covered by the reflected ray on the panel at a particular time is derived.

$$x = \frac{h\ \sin(\alpha - t_r)}{\sin t_r\ \sin(2t_r + \beta - \alpha)} \qquad ----(5)$$

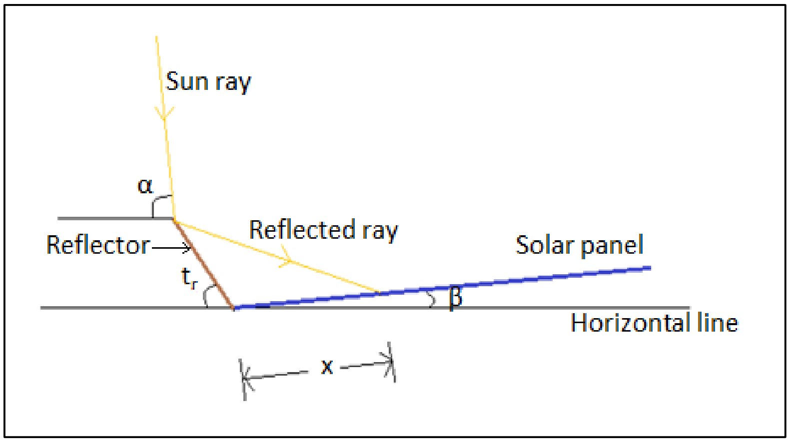

Fig. 8: Reflector Orientation

The assumption that at 12'O clock the "x" become equal to the length of the panel is considered in the equation and calculated the tilt angle of the reflector t_r. The length of the reflector is also estimated with the known value of height (h) and the calculated reflector tilt angle.

VI. RESULTS AND DISCUSSION

The main parameters affecting the performance of the PV panel are solar radiation intensity, temperature, shading and orientation of the panel. Solar radiation can be improved along with optimum panel temperature using plane reflectors. So plane reflectors are the best choice for the CPV power generation. Reflector materials should also be chosen properly. They must reflect the maximum amount of useful incident radiation onto the solar thermal absorbers or the photovoltaic cells.

The canal top solar projects have generated huge interest in India and other parts of the world due to production of pollution-free renewable energy and sparing of water and land. Thus so as to extend the performance of the system reflectors for the concentration of sunlight are suggested.

VII. CONCLUSION

In this paper the concentrated PV system and canal top PV system are combined. As a result the drawback in the concentrated PV system, the decrease in performance due to temperature rise can be avoided. The expected advantage of this proposed system is the reduction of loss of water by evaporation from the canal.

In future work, by making a mini model of the system verify whether performance of the canal top project can be increased by reflecting the solar irradiation. Also check the performance by changing the reflector orientation.

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