Increasing the Yield of PV Panels: A Review

Pankaj Mann
Indian Institute of Management, Lucknow, India
Email: mann56pankaj@gmail.com

Kuldeep Modh
Management Development Institute, Murshidabad, India
Email: kuldeepmodh1995@gmail.com

Suraj Goel
IITRAM, Ahmedabad, India
Email: sgoel01@gmail.com

***Abstract*—With the increasing rate at which fossil fuels are de- pleting, there is a recent advent of technology in solar cells. The efficiency of a typical industrial standard PV panel is around 18- 20% which is quite low. To get more yield different approaches in installation design are there. Here we discussed solar tracking and soiling of PV panels. A comparative study of different implementations is presented. We made a comparison based on these, wherein there are different physical and geographical inputs based on which it suggests what type of PV panel should be installed and what should be done about soiling. From this data we made a tool which guides the people installing PV panels about which tracker and soiling solution they should use. At the end, we presented our own hybrid solar tracking system using image processing.**

***Index Terms*—solar tracking, soiling, image processing**

I. Introduction

With the increased depletion in quantity of fossil fuel available, the application of renewable energy sources has become very popular. On such way is to harvest solar energy. For this purpose, PV panels are available which produce electrical energy. These PV panels are mounted at some particular angle, which is calculated based on the latitude and longitude of the position where they are installed. Such systems are usually referred as fixed axis solar panels. The efficiency of such industrial standard PV panels is around 15-20% [1]. About 1.75107 Joules energy is transmitted from sun every second; now if were to harness this energy for one hour it will meet earth's energy requirement for one year [2]. The mean power consumption of the world as in 2008 was, roughly 15 TW while the total consumption was 474 EJ (1 EJ= 1018 J) [3]. We are capable of producing 35000 times more power using solar energy than we do now with our existing technology [4]. The yield of PV Cells used to be 1% in 1914, increased to 6% in 1954 and according to recent data of 2014 it has reached to 46.5% [5], [6]. Thus, there is a need to increase the efficiency of these systems, so that we can harness more solar energy. There are two ways by which the efficiency of this system can be increased, one is to increase the efficiency of the PV panel by changing its material and another is to change the way these PV panels are installed. Different installation approaches are discussed here such that we get better yield. Here we will find methods which will change the way PV panels are installed. This way we plan to increase the efficiency of the system. Reference [7] tells that incident power on surface will be,

$$P=A\,\lambda\,\sin\theta \tag{1}$$

where A depends on intensity, material constants and surface temperature, λ is the wavelength of sunlight falling on the surface and θ is the angle of inclination of light ray on the plane surface.

A severe threat for the solar panels energy is the soiling of the panels as they get exposed to the sun and direct environment like snow, smog, fog, dust etc. and other problems is increase in temperature and transparency of the panels. The methods used for cleaning and regular maintenance are not viable and if not done on time, reduces the efficiency of the panels. The panels are ineffective to the natural cleaning process like rain and wind as it is uncontrollable and futile [6].

II. Solar Trackers

A. Seasonal Adjustment of Tilt Angle

The position of sun changes throughout the day, and it changes by 23-25 degrees every 22 days [8]. From [7] it is clear that the incident power is dependent on three factors mentioned above, from which we can only change θ, as A and will be fixed for a particular PV panel system. Our goal is change the angle at which sun rays are incident to PV panels, such that sun rays remains perpendicular to the PV panel. The best way to do this is opting for solar tracking systems. These are of two types, single axis (tilt) and dual axis (tilt and azimuthal). O.C. Vilela concluded in his study that the instantaneous solar radiation collected by a tracking based PV panel is more when compared to

Manuscript received August 20, 2018; revised May 10, 2019.

doi: 10.18178/ijoee.7.1.1-7

fixed PV panel [9]. Also there is an estimation that suggests increase in yield of PV panel by 30 to 60 percent using of tracking instead of fixed PV panels [10], and over 40% more power is produced per annum using a variable elevation solar tracker [11]. Over a year there is 29.2% more gain in total solar radiation when we change collectors' azimuth and tilt angles daily with respect to fixed collector with tilt angle calculated based on location [12]. One simple way is to go for seasonal adjustment of tilt angle. To find the optimum date of tilt angle adjustment, we take input data as altitude. In [8] angles are calculated using mathematical equations based on horizontal radiation on PV panel is used. The tracking control system is of two types, open loop control or closed loop control. In open loop control tracking system, we have two ways one is to feed the longitude and latitude of location and let the astronomical equations calculate the position of sun, and other is to feed the sunset and sunrise of particular location to find the position of sun throughout the day and year using simple arithmetic. For closed loop control tracking system we need sensors to give feedback, these will help in identifying the position of sun so that it can be tracked easily. Now generally three different types of sensors are available for tracking purposes which are semiconductor Based/Potentiometer Based, PV panel based, Image processing based. Reference [10] suggests an increment in yield of PV panel by 30-60% using trackers.

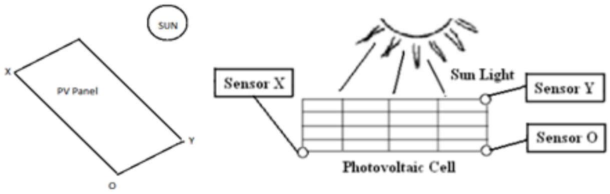

Figure 1. Three photo resistors installed on PV panel [13].

B. *LDR Based Tracker*

Here the sensor will be LDR. To make sensors out of LDR's many different configurations are used. Fig. 2 from [13] shows one such sensor with three LDRs on the surface of a PV panel. Here the three LDRs are X, Y and O where O is the reference LDR, and its resistance will be compared with that of LDR Y and X. Now this data will be sent in microcontroller wherein it compares the two pair's resistance value based on the comparison, it will send signal to motors to move such that there will be no resistance difference between the two pairs. Now by doing so we are insuring that intensity of light is same on O-X and O-Y, which means the sunlight falling on PV panel is perpendicular to the panel. This system showed an increase in efficiency by 63.92%. In addition, the system consumes less power to turn the PV panels as a small PV panel is used instead of a large one [10]. This was a perfect example of dual axis solar tracking system, where LDRs were used to track the azimuth as well as tilt of sun, throughout the year. The above mentioned tracker was dual axis tracking system, it is more precise in tracking but with more precision the complexity of the system increases. So sometimes single tracking systems are also preferred. Angadpreet Singh and Narong Aphiratsakun [14] from Assumption University built an AU solar tracking system. They used single axis tracking system. Fig. 3 shows the design of their tracking sensor which is made using four LDRs separated by an opaque partition. This orientation of LDRs will cast a shadow on the side opposite to the one facing sun, which will drop the resistance value of LDR on the side under the shade. Particularly in [14] authors have used a STM32F4DISCOVERY (Waijung) microcontroller, which can be programmed using Simulink in MATLAB.

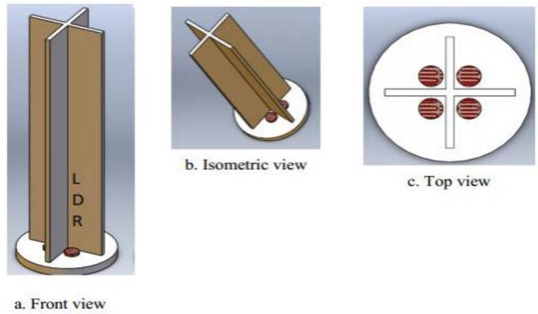

Figure 2. Different views of 4 LDR arrangements in tracking sensor [14].

MATLAB has added advantage of better processing interface and easy programming of system. The resistance reading of four LDRs is used to determine the direction of rotation of DC motor. The values from the left LDRs will averaged and compared with the averaged values from right LRDs to tell the direction of rotation of motor. The tolerance level to stay in the particular orientation can be taken from user [14]. If the difference will be in tolerance level, there will be no rotation and if it is outside the tolerance level the motor will turn.

Here in fixed angle the voltage decreases as sun moves from east to west and in tracking the voltage remains almost constant throughout the day. Now using the same orientation as in [14] Sangamesh Malge et al. made a dual axis tracking system what they did was to move the PV panels in the direction opposite to the shaded LDR for tracking [15]. In [15] the microcontroller used is Beagle Bone Black which has options for network connections which transmit the data from all the LDRs and the tracking status over the network to server. Once the data is on the server, the status of tracking can be monitored from anywhere using the server. The total power produced in a day in case of fixed PV panel system is 2841.49 mW and that of tracking system is 5565.07 mW. A quick calculation on data provided in [15] suggests that there will around 95% increased yield in power production in a day if we employ tracking system. There is an increment in production of solar energy here and the user can monitor the tracking status over a network. Studies performed by N. Othman et .al uses five LDRs [16]. It has five discreet positions for the PV panel, where motor is moved. Corresponding to maximum intensity of each LDR there is a discreet position of motor, when any LDR records maximum intensity (among five), the motor moves to the position corresponding to that LDR. This method is a discreet position tracking system discussed in [16]. The result of the study shows how using tracking method we can achieve more yield than fixed PV panels. For this reason, one should prefer system in [16] for capturing maximum sunlight source for solar harvesting applications.

C. Image Processing Based Tracker

Till now we have discussed only semiconductor based sensors, i.e. LDRs. Using them for tracking sun is disadvantageous because they are highly sensitive to weather conditions particularly on humidity and temperature change as well as rapid deterioration under extreme conditions [17], [18]. Due to this reason, for tracking purposes cameras are used. Images of sun are captured and based on those images tracking is deployed in [19], [20] and [21]. Image processing based trackers use images captured by camera and process them to send signal to motors for tracking sun. R Abd Rahim et .al used Raspberry Pi as microcontroller and image processing module [19]. They connected a camera to the microcontroller and captured images at pre-defined interval of time. The images captured are in grayscale. Using predefined algorithms, the coordinates of centre of sun are calculated. The algorithm here is to orient the camera (mounted on PV panel) such that the centre of sun S(x,y) and centre of image I(x,y) coincides fully. This will ensure that sun rays are perpendicular to the surface, so from [7] it follows that maximum utilization of incident energy takes place. Thus using model in [19] we will get better yield, and even in cloudy weather tracking will happen, whereas this is not in case of LDRs. Instead of using grayscale image, Minor M. Arturo and Garca P. Alejandro used the binary conversion of the image captured by the camera [20]. Fig. 6 shows the binary converted image along with the original image. In [20] a cheap webcam is used for capturing images and MATLAB is used for image processing and motor control. The governing algorithm is similar to that of [19]. Jeongjae Yoo et .al made a hybrid mechanism which makes the use of image processing as well as astronomical equations to track the sun [21]. Using GPS current time, latitude and longitude of tracker is identified, and using astronomical equations with this data current azimuth and altitude angle of sun can be calculated. Here the tracking from astronomical equations will be used as a correction to the tracking by image processing. This method will be advantageous in cloudy weather conditions, where sun will be completely screened off so method discussed in [19] and [20] fails thus astronomical tracking will save the trouble. The three methods of tracking which are discussed above almost same in concept the only difference is that the method in [20] will be more accurate that method of [19] because in [20] the image will be converted into binary image. But the advantage of [19] is that, the tracking can also be done in cloudy weather conditions, but in [20] while converting the image into binary image we will get a complete black image, when sun is screened off [21].

We need tracking even when sun is screened of so that when the sun will again be visible after a duration of say three hours, so that sun doesn't move out of the frame of camera. Exposing the camera lens to sun can be dangerous for the camera itself, so using these cameras pointed at sun is not a good idea. However, if we install suitable filters at the top of camera lens we can use it at places with moderate sunlight. Of course, for the advanced cameras this won't be an issue, but the cost of sensor will increase drastically.

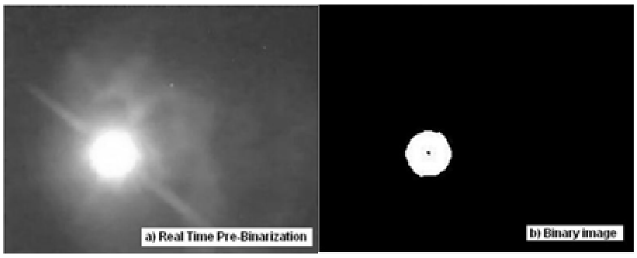

Figure 3. Original image and corresponding binary image [20].

D. PV Panel Based Tracking

Alex Joseph and Kamala J, used a new type of sensor in their tracker, where they orient two PV panels at some angle. The open circuit voltage from the two PV panel is compared with reference value set by the user. If the difference is smaller than the user defined value, there will be no movement and if it is greater than user defined value then tracking is done moving motors such that the voltage difference between the two comes in the range. The hardware is designed keeping in mind the frictional losses due to movement. Here spur gear and worm gears are used to get minimum friction. This method used a different yet effective way of tracking the sun. This sensor doesn't have any disadvantage, as compared to LDR or image processing based trackers. However, this won't be a robust sensor so not a very good tracking method.

E. Water Tracking System

One important application of solar energy is in water heating. Water heating doesn't use PV panels, instead use copper pipe assembly. One such innovative method is used by M. Anish John Paul, where using solar concentration and solar tracking combined together is used to increase the yield of the system [22]. A new effective designed is where a parabolic reflector is used for solar concentration on receiver placed at focus of parabola is used where tracking is done using angular calculations. In tracking altitude and azimuth angle are used directly to move the motors. Due to solar concentration and tracking the temperature of receiver will be increased. The input to the system is radiation received by the reflector surface. It is found in [22] that the efficiency of the system becomes negative after 3 in the noon; this is due to the fact that inside the boiler water will start cooling because solar irradiance decreases after 12:00- 13:00 hours. This system can be used in homes as well as for producing steam if we use large parabolic reflectors [22].

III. Soiling of PV Panels

We will discuss two cleaning methods for solar panels. These methods have been appropriately tested and proven:

A. Active Cleaning Methods

These methods require any external agent or force to overcome soiling or in short, in cleaning of solar panels.

1) Forced air flow from air conditioning system [23]: The method proposed by Ali Assi, Ahmed and all is mostly used in the areas of UAE which could also be implemented various other developed countries where people have a great use of Air conditioners. The PV panels operating above 25 C shows the dependency that the efficiency and output decrease between the values 0.65% /K [24] and 0.4% /K [25], [26]. Fig. 9 depicts the conceptual diagram of the system. The noon temperature of almost 125oC [27] could prove damaging to the panels. Fig. 8 shows results over a year.

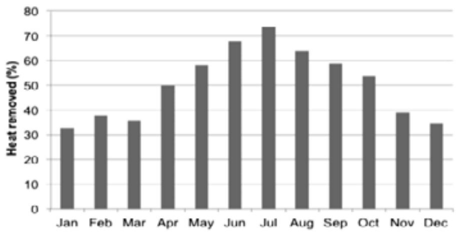

Figure 4. Expected overall heat removes [23].

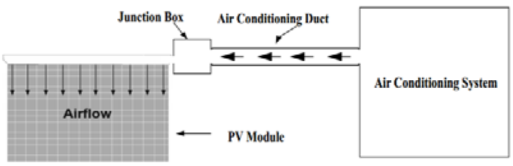

Figure 5. Conceptual diagram of proposed method [23].

2) Electrodynamic screen performance for dust removal [3]: Dust deposits on solar panels causes decrease in the efficiency from 10% to 30% size of the dust particles. Over 90% of dust is detached within two minutes. This method can be put into use in arid, desert regions [28] around the globe. Transparent Electro Dynamic Screens (EDS) [29]-[32], includes parallel electrodes which are transparent and aligned in rows and put within dielectric film or deposited on the top of the cover glass plates of the solar panels. Fig. 10 shows the schematic of EDS.

3) Hydraulic ramp pump method [33]-[35]: The overall efficiency decreases by almost 0.38 % per C [34], so cooling must be good. The given method requires minimal amount of energy to pump water to the top of the panel to clean and cool them down. The schematic is shown is Fig. 11. The Hydraulic RAM Pump consists of two valves that open/close considering the pressure they bear. When the water comes in from the bottom tank, the waste valve will experience high pressure and thus closes itself. The total process works on kinetic energy of water down the panels. Almost 80% of the water goes to waste tank so we need the Tesla Pump [36], to pump the water back to the top tank. This method increases the efficiency by 8%. From measurement 1 (155F) to measurement 2 (89 F) there is power output change from 3483 W to 3977 W.

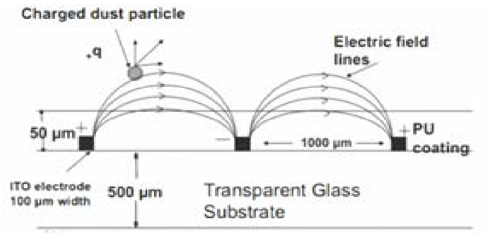

Figure 6. Schematic of electrodynamic screens [3].

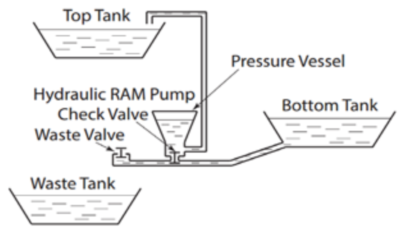

Figure 7. Schematics view of Hydraulic RAM pump [33]-[35].

B. Passive Cleaning methods

These methods do not require any external agent or force to overcome the effect due to soiling or in short, in cleaning of solar panels. They just require some change in orientation or some support to enhance its working.

1) Orientation of vertical photovoltaic panels [6]: Adochitei et .al proposed a method which uses a different geometry in which two vertical photovoltaic panels are put parallel to each other as in Fig. 8. It consists of a mirror prism along 45 degrees. The light from the source is reflected to the solar panels directly. The voltage output in the experiment has indicated that the orientation does not decrease the efficiency but avoid soiling and could be used world-wide.

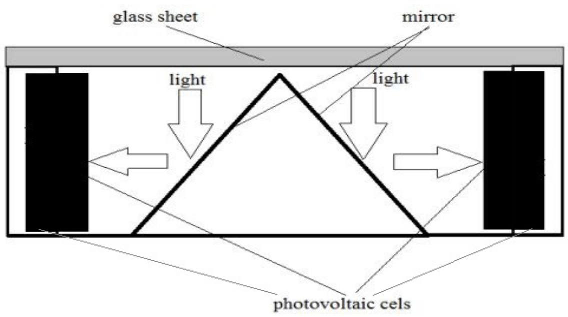

Figure 8. The Vertical Photovoltaic System Schematics [6].

IV. Tracking and Soiling Solutions

We analyzed different tracking and soiling solutions based on the scale of installation, the geographical constraints of the location, and availability of sunlight and other natural resources. Table I and Table II gives a detailed comparison between the different trackers and soiling solution based on investment and location inputs.

TABLE I. COMPARATIVE ANALYSIS OF DIFFERENT SOLAR TRACKERS

Author	Suitable for	Investment	Sensor type	%Increase
Tang [8]	Anywhere	Low	No Sensor	3-5%
Kassem [13]	Arid Region	High	3 LDR's	63.92%
Singh [14]	Arid Region	High	4 LDR's	14.75%
Malge [15]	Arid Region	High	4 LDR's	95%
Othman [16]	Arid Region	High	5 LDR's	19.10%
Rahim [19]	Humid Region	High	Camera	-
Arturo [20]	Humid Region	High	Camera	-
Yoo [21]	Anywhere	High	GPS & Camera	-
Joseph [7]	Anywhere	High	PV panel	-
Anish [22]	Anywhere	Moderate	Direct Data	39%

TABLE II. COMPARATIVE ANALYSIS OF DIFFERENT SOILING METHODS

Method Used	Geographical Preference	Investment	%Increase
Forced Air Flow from Conditioning Systems [23]	Developed countries like UAE, with high dependency on ACs	Moderate	0.4%
Electrodynamic Screen performance for dust removal [3]	Arid Desert regions	High	10-30%
Hydraulic RAM Pump [33]-[35]	Areas with sufficient amount of water and heat	High	8%
Vertical PV Panel [6]	Anywhere	Low	-

We will use the data from the two tables to design an algorithm which will give suggest which type of tracker and soiling solutions would be best for the scenario, and what increase in yield can be expected along with a rough estimate of incremental money the consumer will make once his investment breaks even.

V. HYBRID SOLAR TRACKER

A. *Hardware Design and Operation*

The hardware design includes the Raspberry Pi, two servo motors in pan and tilt position and the webcam. The Raspberry Pi as the main board that processes image and will control the servo motor. The webcam will capture the image from the sky and the will send it to the Raspberry Pi through Universal Serial Bus (USB). The servo motor connected to Raspberry Pi using GPIO port. After locating the position of the sun, Raspberry Pi will move the servo motor, pan or tilt which one are necessary or both so that the sun will positioned at the centre of the image.

If no sun is detected in the image, the Raspberry Pi will move the servo motor until the sun is found. If the sun already at the centre of the image, the Raspberry Pi will give signal to the servo motor to stay at that position for 10 minute.

B. *Image Processing*

Since the image taken from the webcam was a 24- bit colour image, it was converted to 8-bit grayscale colour to allow efficient processing.

The grayscale image was then being converted to binary image in order to detect the circular or curve shape of the sun.

C. *Motor Control*

The movement of servo motor was determined by the Pulse Width Modulation (PWM) signal send from Raspberry Pi. The PWM signals were controlled by the position of the sun in the image. Figure 3 shows the flowchart that analyzes the process of determining the coordinate of the sun by first detecting the shape of sun.

If the sun is not detected on the image due to the webcam facing directly to the sun, Raspberry Pi will send a random acceptant PWM signal to servo motor. This will continuous until the sun is in the image. When the sun is detected, the Raspberry Pi will then analyze the position of the sun. This applies for both pan and tilt motors. If the sun is at the left or right of pan motor, Raspberry Pi will send signal to pan motor signal so that it will position the sun at the centre. If sun is on the left side of the pan and tilt line, then Raspberry will give PWM signal to move the pan servo motor so that the pan line comes across the centre of the sun. The same processes apply to tilt servo motor.

After the sun is at the centre of the image, the Raspberry Pi will continuously send the same PWM signal for 10 minute. This is a closed-loop system application where the output will determine the input.

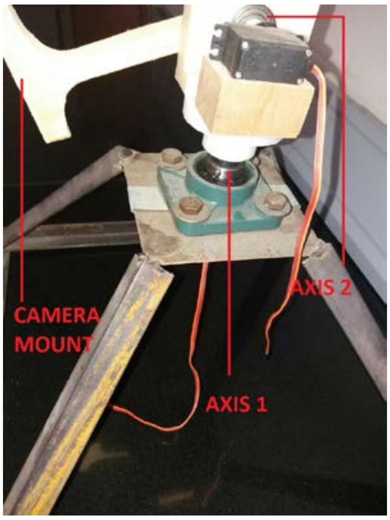

Figure 9. The solar tracker design.

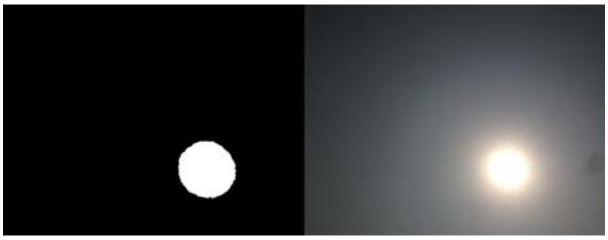

Figure 10. Original image and corresponding binary image.

D. Results of the Study

From this work, an image-based solar tracking system using Raspberry Pi was proposed. It was shown that the system works very well with the webcam aided with image processing embedded in Raspberry Pi board always manage to catch the position of the sun even during the cloudy day. This will certainly result in maximum harvesting of solar energy. The system offers simple implementation of the tracker with the capability to locate the central coordinate of the sun on an image and the Raspberry Pi will send signal to the motor that will rotate accordingly follow the movement of the sun.

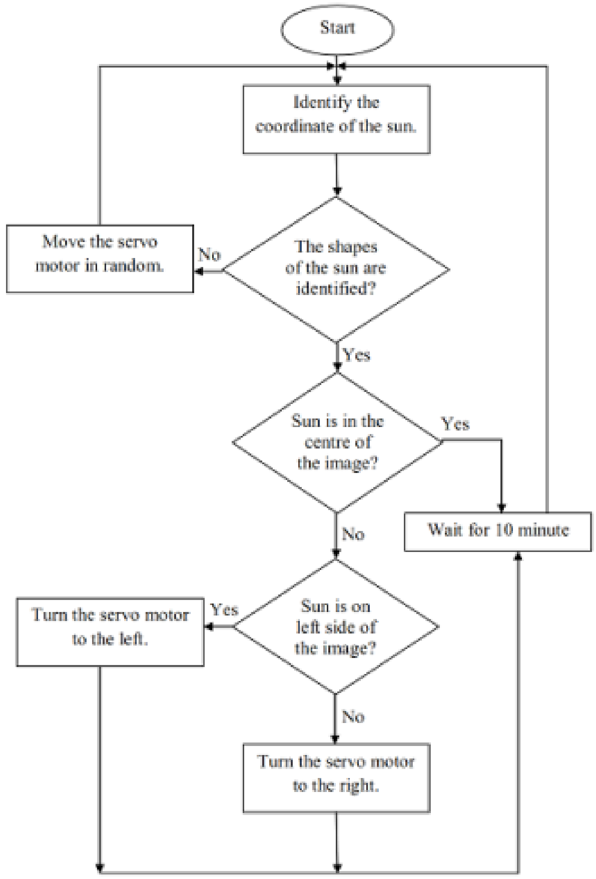

Figure 11. The flow of motor servo operation.

VI. Conclusion

We have seen various trackers, and each tracker has its importance based on the location and requirement, the best tracker for large scale will be an image processing based tracker with maximum tracking point data transmission over a network. Same goes with the soiling solution, where the methods are scrutinized based on the use and the place of installation of PV panels. The best method is of Vertical Photovoltaic Panels that are economically viable and totally nullifies the problem of soiling and efficiency of the panels is unharmed. Unlike the self-cleaning methods which could be futile as they are unreliable and uncontrollable. Table I and Table II show a quick comparison between the tracking systems and soiling solutions discussed until now. Based on the tables presented we can sort which tracker/soiling solution is best for which type of investment and suitable for which location. Based on the findings we developed a new hybrid tracking system which will track the sun throughout the day over a year.

References

[1] S. Malge, K. Bhole, and R. Narkhede, "Designing of Dual- axis Solar Tracking System with Remote Monitoring" in *Proc. 2015 International Conference on Industrial Instrumentation and Control(ICIC)*, 2015.

[2] L. Rosetti, "Thed designing, building, and testing of an azimutha-altitude dual axis solar tracker," B.A dissertation, Dept. of Physics and Astronomy, Pomona College,California, May 2012.

[3] M. Mazumder, *et al.*, "Characterization of electrodynamic screen per- formance for dust removal from solar panels and solar hydrogen generators," *IEEE Transactions on Industry Applications*, vol. 49, no. 4, pp. 1793-1800, 2013.

[4] M. S. Islam, M. Hoq, M. A. S. Haque, M. A. R. Akand, M. R. Hasan, and M. K. Basher, "Challenges and prospects of cost-effective Si-based solar cells fabrication in Bangladesh," in *Proc. 2014 International Conference on Electrical Engineering and Information & Communication Technology (ICEEICT)*, Dhaka, 2014, pp. 1-6.

[5] Tibbits, P. Beutel, E. Oliva, C. Karcher, G. Siefer, F. Dimroth, *et al.*, "New efficiency frontiers with wafer-bonded multi-junction solar cells," in *Proc. 29th European PV Solar Energy Conference and Exhibition, Amsterdam*, The Netherlands, 2014.

[6] M. Adochitei, C. Harabagiu, D. Astanei, and R. Burlica, "A new solar energy converting system with vertical photovoltaic panels," in *Proc. 2014 International Conference and Exposition on Electrical and Power Engineering (EPE)*, Iasi, 2014, pp. 1129-1131.

[7] A. Joseph and J. Kamala, "Economic and backlash tolerable solar tracking system," in *Proc. 2013 International Multi-Conference on Automation, Computing, Communication, Control and Compressed Sensing (iMac4s)*, Kottayam, 2013, pp. 748-753..

[8] R. Tang and X. Liu, "Installation design of solar panels with seasonal adjustment of tilt-angles," in *Proc. 2010 Asia-Pacific Power and Energy Engi- neering Conference*, Chengdu, 2010, pp. 1-4.

[9] O. C. Vilela, N. Fraidenraich, and C.Tiba, "Photovoltaic pumping systems driven by tracking collectors," *Experiments and Simulation Solar Energy*, vol. 74, no. 1, pp. 45-52, 2003.

[10] A. K. Saxena and V. Dutta, "A versatile microprocessor based controller for solar tracking," in *Proc. IEEE Conference on Photovoltaic Specialists*, Kissimmee, FL, 1990, pp. 1105-1109.

[11] A. Yazidi, F. Betin, G. Notton, and G. A. Capolino, "Low cost two-axis solar tracker with high precision positioning," in *Proc. 2006 First International Symposium on Environment Identities and Mediterranean Area, Corte- Ajaccio*, 2006, pp. 211-216.

[12] V. H. Morcos, "Optimum tilt angle and orientation for solar collectors in Assiut, Egypt," *Renewable Energy*, vol. 4, no. 3, pp. 291-298, Apr. 1994.

[13] A. Kassem and M. Hamad, "A microcontroller-based multi-function solar tracking system," in *Proc. 2011 IEEE International Systems Conference*, Montreal, QC, 2011, pp. 13-16.

[14] A. Singh and N. Aphiratsakun, "AU solar tracking system," in *Proc. 12th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CN)*, Hua Hin, Cha-am, Thailand, 2015, pp. 1-4.

[15] S. Malge, K. Bhole, and R. Narkhede, "Designing of dual-axis solar tracking system with remote monitoring," in *Proc. 2015 IEEE Industrial Instrumentation and control Conf.*, 2015, pp. 1524-1527.

[16] N. Othman, M.I.A. Manan, Z. Othman, and S.A.M. Al Junid, "Performance Analysis of Dual-axis Solar Tracking System," in *Proc. 2013 IEEE Control System, Computing and Engineering Conf.*, 2013, pp. 370-375.

[17] M. Taki, Y. Ajabshirchi, H. Behfar, and M. Taki, "Ex- perimental investigation and construction of PV solar tracker control system using image processing," *Modern Applied Science*, vol. 5, no. 6, Dec. 2011.

[18] P. J. Hession and W. J. Bonwick, “Experience with a sun tracker system,” *Solar Energy*, vol. 32, no. 1, pp. 3-11, 1984.
[19] R. Abd Rahim, M. N. S. Zainudin, M. M. Ismail, M. A. Othman, “Image-based solar tracker using raspberry Pi,” *Journal of Multidisciplinary Engineering Science and Technology*, vol. 1, no. 5, pp. 369-373, Dec. 2014.
[20] M. M. Arturo and G. P. Alejandro, “HighPrecision solar tracking system,” in *Proc. 2010 IAENG World Congress on Engineering Conf.*, 2010, pp. 844-846.
[21] J.Yoo and Y. Kang, B. Song, and J. Song, “Solar tracking system experimental verification based on GPS and vision sensor fusion,” *Journal of Automation and Control Engineering*, vol. 2, no. 4, pp. 417-421, Dec. 2014.
[22] M. Anish John Paul, ”Design and performance analysis of automated two axis solar tracking system for steam generation,” in *Proc. 2013 International Conference on Energy Efficient Technologies for Sustainability (ICEETS)*, Nagercoil, 2013, pp. 432-437.
[23] A. Assi, A. Hassan, M. Al-Shamisi, and H. Hejase, “Removal of air blown dust from photovoltaic arrays using forced air flow of return air from air conditioning systems,” in *Proc. International Conference on Renewable Energies for Developing Countries (REDEC)*, Beirut, 2012, pp. 1-5.
[24] E. Radziemska, “The effect of temperature on the power drop in crystalline silicon solar cells,” *Renewable Energy*, vol. 28, vol. 1, pp. 1-12, Jan. 2003.
[25] H. A. Weakliem and D. Redfield, “Temperature dependence of the optical properties of silicon,” *Journal of Applied Physics*, vol. 50, pp. 1491-1493, 1979.
[26] S. Krauter, “Actual optical and thermal performance of PV-modules,” in *Proc. IEEE 1st World Conference on Photovoltaic Energy Conversion - WCPEC (A Joint Conference of PVSC, PVSEC and PSEC)*, 1994, vol. 1, pp.734-737.
[27] Y. F. Nassar, and A. A. Salem, “The reliability of the photovoltaic utilization in southern cities of Libya,” *Desalination*, vol. 209, no. 1-3, pp. 86-90, 2007.
[28] K. Kurokawa, *Energy from the Desert*, London, UK: Earth Scan, 2007.
[29] J. R. Melcher, “Traveling- wave induced electro-convection,” *Phys. Fluids*, vol. 9, no. 8, pp. 1548-1555, 1966.
[30] S. Masuda, “Electric curtain for confinement and transport of charged aerosol particles,” in *Proc. Albany Conference on Electrostatics*, 1971.
[31] S. Masuda, K. Fujibayashi, K. Ishida, and H. Inaba, “Confinement and transportation of charged aerosol clouds by electric curtain,” *Electronic Engineering in Japan*, vol. 92, pp. 9-18, 1972.
[32] F. M. Moesner and T. Higuchi, “Traveling electric field conveyor for contactless manipulation of micro parts,” in *Proc. IEEE Industry Applications, Society, Annual Meeting*, New Orleans, 1997, vol. 3, pp. 2004-2011.
[33] W. J. C. Melis, S. K. Mallick, and P. Relf, “Increasing solar panel efficiency in a sustainable manner,” in *Proc. IEEE International Energy Conference (ENERGYCON)*, 2014, Dubrovnik, Croatia.
[34] D. J. C. MacKay. (February 2016). *Sustainable Energy - Without the Hot Air*. [Online]. Available: http://withouthotair.com
[35] Wikipedia contributors. (2016). Hydraulic ram-Wikipedia, The Free Encyclopedia. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Hydraulic_ram&direction=next&oldid=720725178
[36] Wikipedia contributors. (2016). Tesla turbine. Wikipedia. The Free Encyclopedia, [Online]. Available: https://en.wikipedia.org/w/index.php?title=Tesla_ turbine&oldid= 710744361¿

Pankaj Mann Pankaj is a researcher and an innovator; he is pursuing his masters from IIM Lucknow. His current research interest is in supply chain and he has worked for the sales and marketing division of Asian Paints. He has exposure to supply chain, operations and sales and marketing. He has a Go-getter instinct and has a patents and several published papers to his name. He is active in brainstorming various marketing and strategy events in IIM Lucknow. His logical reasoning and decision making skills puts him out of the crowd.

Kuldeep Modh Kuldeep is currently pursuing his MBA from MDI Gurgaon (Murshidabad), India. He was a Business Development Manager at Interiors info E Commerce LLP and has experience in Electrical Engineering Field at Gujarat State Fertilizers and Chemicals. He is a graduate from IITRAM, Ahmedabad. He has got exposure to sales, marketing, and business development and had responsibility to manage teams. He has involved himself into operations of the company. He is extremely positive, calm, responsible and startup enthusiast with entrepreneurial instincts. He is associated with Techno-cultural event as Secretary and responsible for various projects at IITRAM. His managerial skills and result driven attitude has been very helpful for company.

Suraj Goel Suraj is working as a Member of Technical Staff at Qubole. He has been given responsibility to handle one module of UI (Clusters page) functionality in company's product. He is actively involved in frontend development and corresponding Middleware development of things. The tech stack he is currently working on is Ember JS (on frontend side) and Ruby on Rails on (Middleware side). He is highly enthusiastic regarding technology and considers himself as a person who can learn very quickly. He has been able to get a Full time opportunity at Qubole within 2 months tenure of internship. He is good in analytical and logical skills which help him to solve any query quickly.