A Mechanical Design of an Altitude-Azimuth Two Axis Solar Tracking System for Sakarya, Turkey

C. A. Tırmıkçı and C. Yavuz
Eng. Dept, Faculty Electrical and Electronics Eng., Esentepe Campus, Sakarya University, Serdivan, Sakarya, Turkey
Email: {caksoy, cyavuz}@sakarya.edu.tr

***Abstract*—This paper presents a mechanical design of an altitude-azimuth two axis solar tracking system for Sakarya province, Turkey. The design consists of a solar panel, two linear actuators and linkages. The main objective of this work is to build a mechanical construction: cost effective, durable to withstand the weather conditions of Sakarya; easy to assemble; easy to move; long-lasting with no maintenance; capable to track the sun's position in both altitude and azimuth axis.**

***Index Terms*—altitude, azimuth, linear actuator, solar tracking**

I. Introduction

Turkey is a developing country with a population of 77,695.904 million [1]. The primary energy demand of the country is recorded 121 million TPE in 2012 [2]. A considerable part of this demand has been met by fossil fuels: 31% from coal, 31% from natural gas, 25% from oil [2]. 99% of the natural gas demand, 95% of coal demand and 92% of oil demand is met by imports since the fossil fuel reserves of the country are incapable to meet the total demand [3]. It is clear that Turkey is heavily dependent on imported fossil fuels. This dependency harms the country's economy negatively as well as the environment. It is recorded that greenhouse gas emissions have increased 124% between 1990 and 2011 and reached to 422, 42 million metric tons of carbon dioxide [2]. The increase in greenhouse emissions is directly proportional to increase in burning fossil fuels. In 2011 fossil energy based emissions of Turkey are recorded as 286 million metric tons of carbon dioxide, 0.91% of the total emissions in the world and 2.32% of the total emissions in OECD [2]. Thus it is one of the country's prior future goals to localize the energy sources for a sustainable growth.

Turkey has a favorable geographical position with an enormous energy potential, more than 495 terrawatt hours per year (TWh/year) [4] and [5]. Renewable energy resources that contribute this potential are biomass energy with potential of 196.7 TWh/year, hydropower with potential of 125 TWh/ year, solar energy with potential of 102.3 TWh/year, wind energy with potential of 50 TWh/year and geothermal energy with potential of 22.4 TWh/year [4] and [5]. Among all solar energy is a prominent alternative for Turkey with a potential of 3.6 kWh/m^2-day [1]. This potential is utilized effectively in hot water heating with approximately 8 GWh installed capacity, third largest capacity in the world [6]. However the utilization in power generation is negligible. It is vital for the government to encourage the investment and studies in solar energy with effective energy policies to expand the solar energy utilization in power generation to break the dependency on imported fossil fuels [7].

A PV panel is a device that converts the solar energy into electricity or heating. To increase the amount of output power from PV panels, solar tracking systems are used to minimize the angle of incidence between the incoming sunlight and the PV panel [8]. There are two types of solar tracking systems: single axis tracking systems and two axis tracking systems. The increase of the output power from the PV module is up to 20% compared to a fixed module with single axis tracking [9] and [10], while it is up to 30% with two axis tracking [11]-[13]. Different types of two axis solar tracking systems have been proposed in current studies. Roth, et al. designed an altitude-azimuth tracking system measuring direct solar radiation with a pyrheliometer and providing movement with two stepper motors [14]. Barker, et al. presented a low-profile two axis tracking system with new actuation geometry comprising of two coplanar and perpendicular linear actuators [15]. Fathabadi suggested a sensorless altitude-azimuth tracking system with a tracking error of 0.43˚ [16]. Batayneh et al. presented an altitude-azimuth tracking system controlled by a fuzzy controller [17]. Yao et al. designed a declination-clock mounting system with normal tracking strategy and daily adjustment strategy consisting of two linear actuators [18].

The primary purpose of this work is to establish a novel mechanical design of an altitude-azimuth two axis solar tracking system for Sakarya province, Turkey. For this purpose a configuration of a PV panel and two linear actuators is constituted and developed according to weather conditions and solar angle values of Sakarya in Solidworks environment. Then materials for mechanical construction are selected. The key parameters used for selecting the parameters are to be cost effective, durable and long lasting. Finally the assembly of the mechanical

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system is performed in accordance with the design developed in Solidworks.

II. Solar Angles

Azimuth is the angle between north vector and the projection of the sun down onto the horizon while the altitude is the angle between the sun and the horizon (Fig. 1).

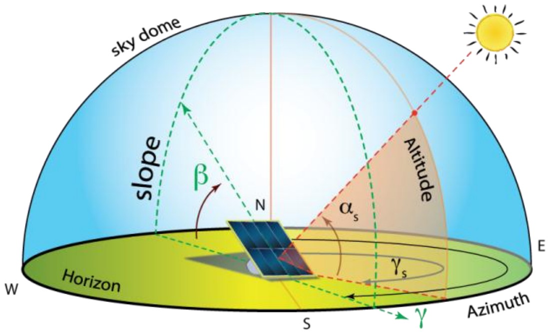

Figure 1. Definition of azimuth and altitude angles.

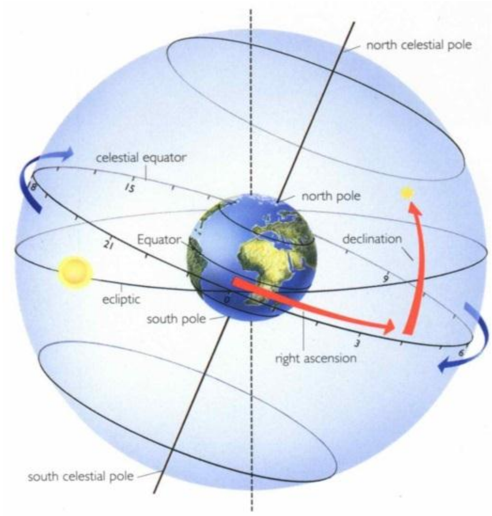

Figure 2. Definition of declination angle.

Azimuth angle is measured clockwise from the north vector between 0° and 360°. North, the reference plane, has azimuth 0°, east has azimuth 90°, south has azimuth 180° and west has azimuth 270°. Altitude angle is measured between 0° and 90°. Different formulas are presented for azimuth angle and altitude angle in current studies. The formulas used in this paper are as follows [19]:

$$azi = \cos^{-1}\left(\frac{\cos lat * \sin dec - \cos dec * \sin lat \cos HRA}{\cos alt}\right) \quad (1)$$

$$alt = \cos^{-1}(\sin dec * \sin lat + \cos dec * \cos lat * \cos HRA) \quad (2)$$

where *azi* is the azimuth angle, *alt* is the altitude angle, *lat* is the latitude, *dec* is the declination angle and *HRA* is the hour angle. Declination expresses the angle between the equator and the ecliptic (Fig. 2). Hour angle is the difference between solar local time and solar noon. In this work declination and hour angles are calculated by the equations below [19]:

$$\begin{aligned} dec &= 0.33281 - 22.984 * \cos N + 3.7872 * \sin N \\ &-0.3499 * \cos 2N + 0.03205 * \sin 2N \\ &-0.1398 * \cos 3N + 0.07187 * \sin 3N \end{aligned} \quad (3)$$

$$HRA = 15 * (hour - 12) \quad (4)$$

where N is the number of the day according to the calendar.

III. Tracking System Design in Solidworks

In the presented design axis movement of the tracking system is provided by two linear actuators. A linear actuator is a device that converts the circular motion of an electric motor into linear motion (Fig. 3). The durability and long lifetime without any maintenance of actuators are reasons of preference in solar applications lately. The specifications of the actuators used in this work are given in Table I.

Figure 3. Linear actuator selected for the proposed tracking system.

TABLE I. Linear Actuator Specifications

Input Voltage (VDC)	24 (tolerance 18-32)
Maximum Stroke Length (mm)	300
Maximum Dynamic Load (N)	600
Maximum Static Load (N)	1300
Maximum No Load Speed (mm/s)	30
Maximum Full Load Speed (mm/s)	20
Screw/Nut Type	Ball bearing with ball/ load lock
Operating Temperature (°)	-25 to +65
Protection Class	IP44
Actuator Weight (kg)	2

The specifications of the PV panel selected for the design are given in Table II.

TABLE II. PV Panel Specifications

Panel Size	668mm(w)x89 mm(h)x34mm(d)
Weight	7.6kg
Peak Power	80W
Open Circuit Voltage	21.5V
Short Circuit Current	5.1A
Power Allowance Range	5%
Maximum Power Voltage	17.5V
Maximum System Current	4.58A
Maximum System Voltage	700VDC
Number of Cells	36

The configuration of the actuators and the PV panel is determined in Solidworks environment in accordance with standards below:

- EN 1991-1-3:Snow Loads
- EN 1991-1-4:Wind Actions
- IN 1990: Structural Calculations
- EN 1993-1-8: Design of Joints

Fig. 4 shows the proposed tracking system design in Solidworks. The behaviour of the design is simulated for the parameters below:

- The durability under the weather conditions of Sakarya,
- The rotation abilities of two axis to follow the sun's position in Sakarya.

Finally the assembly drawings of the design are created to ease the mounting stage of the work (Fig. 5).

Figure 4. The proposed altitude-azimuth two axis solar tracking system design in Solidworks.

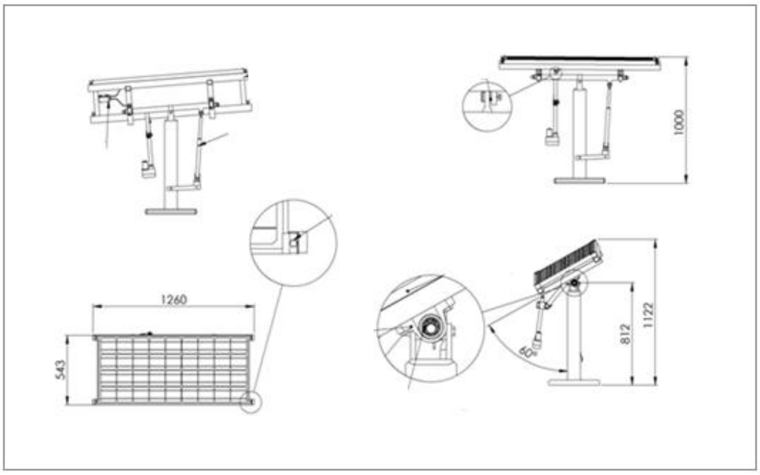

Figure 5. Assembly drawings of the proposed system design in Solidworks.

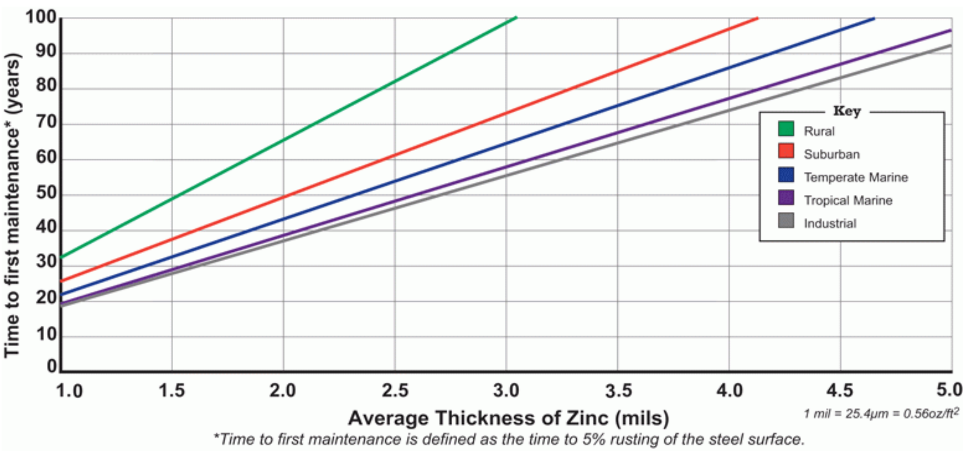

Figure 6. HDG's time to first maintenance time for different environments.

IV. Application of the Proposed Design

The undercarriage of the mechanicalconstruction is constructed from hot dip galvanised (HDG) steel metal.Hot dipgalvanized steel providescorrosion resistance without the cost of stainless steel, and is considered superior in terms of cost and life-cycle. The process can occur only on a clean surface. Therefore the steel goes through a thorough chemical clean before the process where all rust, oil and mill scale are removed from the surface. When the cleaning process is completed, the coating process begins. The steel is dipped into the molten zinc at around 460 ℃ temperature. When the galvanising process is complete, the steel is left to cool in a quench tank. Finallythe metallurgical process begins where the zinc coating is bonded to the steel. The advantages of hot dip galvanizing process are as follows [20]:

- Long lifetime

- Low cost
- Reliability
- Ease of application
- Environmentally friendly

Fig. 6 shows HDG's time to first maintenance for different territories [20]. From the figure, it is observed that HDG rarely needs maintenancewithout any special protection even in industrial environments.

A special aluminium mounting frame is utilized for the top of the mechanical construction, solar panel frame (Fig. 7). The frame is selected a flexible slide in construction that reduces installation time and equipment cost with the elimination of the clamps and brackets. Besides the weather resistance of the frame contributes system durability and aesthetics looking clean and neat for a long time without any additional painting or maintenance.

Figure 7. Aluminium mounting frame for the solar panel.

Nuts and bolts made of steel with strength of 8.8 and in accordance with TS EN ISO 898-1are utilized for assembling the whole mechanical body. Proof loads for the bolts used in this work are given in Table III.

TABLE III. PROOF LOADS FOR THE BOLTS

Size	Load (*kg*)
M6	1,160
M8	2,120
M10	3,370
M16	9,100

When the assembly is completed, the system is settled on locking carters (Fig. 8 and Fig. 9).

Figure 8. The front view of the proposed altitude-azimuth two axis solar tracking system design.

Figure 9. The back view of the proposed altitude-azimuth two axis solar tracking system design.

V. RESULTS AND DISCUSSIONS

TABLE IV. WIND STATISTICS FROM SAKARYA

Months	Wind Probability (%)	Average Wind Speed (km/h)
January	6	9.26
February	5	9.26
March	8	11.11
April	8	11.11
May	5	11.11
June	6	11.11
July	8	12.96
August	8	11.11
September	9	11.11
October	3	9.26
November	3	7.41
December	2	7.41

TABLE V. MONTHLY MEAN RAINFALL AMOUNT FOR SAKARYA[KG/M^2]

January	February	March	April	May	June	July	August	September	October	November	December
93.6	75.4	75.9	59.1	49.9	69.6	48.6	45.2	54.0	79.6	77.8	105.9

TABLE VI. WIND SIMULATION RESULTS OF THE PROPOSED DESIGN

Wind Speed [*km/h*]	Displacement [*mm*]
7	0.00
8	0.00
9	0.00
10	0.00
11	0.00
12	0.00
13	0.00
14	0.00
15	0.00
20	0.00
25	0.01
30	0.02

TABLE VII. RAINFALL SIMULATION RESULTS OF THE PROPOSED DESIGN

Pressure [kg/m^2]	Displacement [*mm*]
30.00	0.00
40.00	0.01
50.00	0.02
60.00	0.02
70.00	0.02
80.00	0.03
90.00	0.03
100.00	0.04
120.00	0.04

It is vital for a mechanical system to resist the physical conditions of its environment. Sakarya is a province located on the coast of Black Sea in Marmara region, Turkey. Both Black Sea climate and Marmara type Mediterranean climate are observed in the province. The northern part of the province expresses the characteristics of Black Sea climate, colder and wetter. The climate in southern part is warmer, drier and less affected by humidity with the effect of the Mediterranean climate. The greatest monthly mean wind speed and rainfall for the province is recorded12.96*km/h* (Table IV) and 105.9 kg/m^2 (Table V) respectively [21] and [22]. The durability of the presented design is simulated for those maximum values. The simulation results show that the system moves maximum 0.04 mm under these conditions (Table VI and Table VII).As mentioned in Section II the materials of the mechanical construction, aluminum and HDG, contributes the system to withstand the related weather conditions since they are all weather resistant.

TABLE VIII. ALTITUDE ANGLE(°) AND AZIMUTH ANGLE (°) VALUES FOR A SPECIFIC DAY FROM EACH SEASON

	19.06.2016		19.10.2016		19.01.2016		19.04.2016	
Time	Altitude	Azimuth	Altitude	Azimuth	Altitude	Azimuth	Altitude	Azimuth
07:00	15.1	71.9	-3.5	100.4	-	-	7.9	81.8
08:00	26.1	80.7	7.6	110.3	-4.1	113.6	19.2	91.4
09:00	37.4	89.9	17.7	121.3	6.0	123.5	30.5	101.9
10:00	48.7	100.7	26.7	133.9	14.8	134.7	41.3	114.2
11:00	59.5	115.5	33.8	149	21.9	147.4	50.9	130.4
12:00	68.6	139.6	38.1	166.4	26.8	161.9	58.0	152.7
13:00	72.7	180.1	38.9	185.3	28.8	177.6	60.6	181.3
14:00	68.6	220.6	36.0	203.6	27.7	193.5	57.6	209.5
15:00	59.5	244.7	30.1	219.7	23.7	208.5	50.7	231.3
16:00	48.7	259.3	21.8	233.3	17.1	221.7	40.4	247.0
17:00	37.4	270.1	12.1	244.9	8.8	233.3	29.6	259.2
18:00	26.1	279.4	1.7	255.2	-1.0	243.6	18.3	269.5

The rotation ability of a solar tracking system is the determining parameter in performing the tracking accurately. The simulation results show that maximum rotation limits for altitude and azimuth angle of the presented design are 6˚ and 260˚ respectively. The daily azimuth and altitude values of Sakarya for a specific day from each season are given in Table VIII. According to the table, the mechanical construction of the design allows tracking between 08:00 am - 17:00 pm in summer and autumn, 09:00 am - 17:00 pm in winter and 07:00 am - 17:00 pm in spring. This result is an important input when programming the control unit of the system to maximize the output power of the system.

In designing solar systems, it is one of the main objectives to low the system cost. Mounting and maintenance costs constitute a significant part of the total cost. In Section III mounting costs are reduced by the assembly drawings developed to perform the mounting stage with few workers. In Section IV maintenance costs are eliminated by selecting all materials long-lasting without any maintenance.

VI. Conclusion

In this paper an altitude-azimuth two axis solar tracking system design for Sakarya province, Turkey is performed. The mechanical construction of the system is specified according to the weather conditions and the solar angle values of the province in Solidworks. Then required mechanical components are determined and the system is built accordingly. The results show that:

- The mechanical constructionis durable for the worst weather conditions of the province,
- All components of the mechanical construction are in accordance with the standards, long-lasting and rarely need maintenance.
- The rotation limits of the two axis are measured 6˚ and 260˚. These limits allow the tracking between 08:00 am - 17:00 pm in summer and autumn, 09:00 am - 17:00 pm in winter and 07:00 am - 17:00 pm in spring.
- The mounting stage is eased by selecting practical components and preparing assembly drawings in designing stage. Two workers can easily assembly all components in ten minutes of time.
- The system can be moved easily and safely by the use of locking carters.

From these results it can be concluded that the mechanical system designed and built in this paper can be used optimally with a control unit addition for Sakarya province and the regions adjacent to it. The next step of this work is to develop the control unit and examine the efficiency of the system.

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References

[1] Turkish Statistical Institute, (TUIK), "Population projections". (http://www.tuik.gov.tr/UstMenu.do?metod=temelist, 2014) [Accessed date on January 2017].
[2] World Energy Council Turkish National Committee, "Energy Report 2013," January 2014.
[3] Turkish Electricity Generation Company (EUAS), "Electricity generation sector report 2012," Ankara, Turkey, EUAS, 2013.
[4] F. Evrendilek and C. Ertekin, "Assessing the potential of renewable energy sources in Turkey," *Renewable Energy*, vol. 28, pp. 2303-2315, 2003.
[5] Z. B. Erdem, "The contribution of renewable resources in meeting Turkey's energy-related challenges," *Renewable and Sustainable Energy Reviews*, vol. 14, pp. 2710-2722, 2010.
[6] S. O. Topkaya, "A discussion on recent developments in Turkey's emerging solar power market," *Renewable and Sustainable Energy Reviews*, vol. 16, pp. 3754-3765, 2012.
[7] C. Aksoy Tırmıkçı and C. Yavuz, "Performance evaluation of a 295 kWp grid connected photovoltaic system in Kocaeli, Turkey," in *Proc. International Conference on Green Technologies and Energy Efficiency*, 2016, pp. 92-97.
[8] C. Aksoy Tırmıkçı and C. Yavuz, "Comparison of solar trackers and application of a sensor less dual axis solar tracker," *Journal of Energy and Power Engineering*, vol. 9, pp. 556-561.
[9] A. Al-Mohammad, "Efficiency improvements of photo-voltaic panels using a sun-tracking system," *Applied Energy*, vol. 79, no. 3, pp. 345-354, 2004.
[10] S. Abdallah and O. Badran, "Sun tracking system for productivity enhancement of solar still," *Desalination*, vol. 220, pp. 669-676, 2008.
[11] R. Mamlook, S. Nijmeh, and S. Abdallah, "A programmable logic controller to control two axis sun tracking system," *Informaion Technology Journal*, vol. 5, no. 6, pp. 1083-1087, 2006.
[12] R. Eke and A. Senturk, "Performance comparison of a double-axis sun tracking versus fixed PV system," *Solar Energy*, vol. 86, pp. 2665-2672, 2012.
[13] C. Sungur, "Multi-axes sun tracking system with PLC control for photovoltaic panels in Turkey," *Renewable Energy*, vol. 34, pp. 1119-1125, 2009.
[14] P. Roth, A. Georgiev, and H. Boudinov, "Cheap two axis sun following device," *Energy Conversion and Management*, vol. 46, no. 7-8, pp. 119-1192, 2005.
[15] L. Barker, M. Neber, and H. Lee, "Design of a low profile two-axis solar tracker," *Solar Energy*, vol. 97, pp. 569-576, 2013.
[16] H. Fathabadi, "Novel high efficient offline sensorless dual axis solar tracker for using in photovoltaic systems and solar concentrators," *Renewable Energy*, vol. 95, pp. 485-494, 2016.
[17] W. Batayneh, A. Owais, and M. Nairoukh, "An intelligent fuzzy based tracking controller for a dual-axis solar PV system," *Automation Constr*, vol. 29, pp. 100-106, 2013.
[18] Y. Yao, Y. Hu, S. Gao, G. Yang, and J. Du, "A mulipurpose dual-axis solar tracker with two tracking strategies," *Renewable Energy*, vol. 72, pp. 88-98, 2014.
[19] S. Szokolay, "Solar geometry," Queensland: PLEA (Passive and Low Energy Architecture International), 2007.
[20] Time to First Maintenance. Available: https://www.galvanizeit.org/hot-dip-galvanizing/how-long-does-hdg-last/in-the-atmosphere/time-to-first-maintenance[Accesed February 2017].
[21] Wind Statistics. Available: https://www.windfinder.com/windstatistics/kocaeli_izmit?fspot=bakacak_pamukova_sakarya [Accessed February 2017].
[22] https://www.mgm.gov.tr [Accessed February 2017].

C. Aksoy Tırmıkçı was born in Denizli on November 2, 1988.She received the B.Sc. degree and M.Sc. degrees from Ege University in 2011 and Sakarya University 2013 respectively. Her present research interests are photovoltaic system applications.

She joined the Electrical and Electronics Engineering Department at Sakarya University in 2012 where she is a research assistant now.

Cenk Yavuz was born in Sakarya on July 3, 1979. He received the B.Sc., M.Sc. and Phd. degrees from Sakarya University in 2002, 2004 and 2010 respectively. His present research interests are PV systems, renewable energy sources, lighting design, energy efficiency and quality.

He joined the Electrical and Electronics Engineering Department at Sakarya University in 2002, where he is an Assistant Professor Dr. since 2010.

Dr. Yavuz is a longtime member of Turkish National Committee of Illumination and has several international publications on different subjects of Electrical Engineering.