LAB University of Applied Sciences

Development of the 2D-axis system for solar panels

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Abstract

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Title of the thesis

Development of the 2D-axis system for solar panels and research of final result

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Mechanical Engineering and Production Technology

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Abstract

The objective of this research was to design and evaluate a 2D-axis moving system for solar panels, and to compare the performance of panels that can consistently face the sun to those that do not have this capability. The study included a comprehensive analysis of the benefits and limitations of the system, and the results demonstrated its effectiveness in maximizing energy output. The findings of this research provide strong justification for the use of this system and emphasize its importance in optimizing the performance of solar panels.

Keywords

Solar panels, Solidworks, development, electricity.

Contents

1 Introduction

From ancient ages people have been developing separate ways for using energy from nature. There have been separate ways like water wheel or windmill. At the same time were aware of strange force known as an electricity, but they did not understand it. As time passed, technology advanced and the principles of electricity and its collection were researched by Nicola Tesla and Thomas Edison it changed entire world vision about technologies and what is that. There were plenty ways to produce electricity, such as using coal, wood, gas etc. The only problems of this methods are that all those resources are limited and eventually running out. With understanding of that engineers started thinking about getting energy from resources which is not limited and at some point, were developed principles of getting electricity from wind, water, and sun since it is unlimited resources which is given by mother nature.

Main goal of study is to develop 2D-axis system for solar panel stand that allows panel face sun all the possible time to get as much energy as possible. The system will be designed to be as stable and secure as possible, considering various conditions. Justification of this systems and its use will be proved with simulation of complete system in SolidWorks FEM testing.

This thesis will explain how solar panels (Figure 1) work, how they can be upgraded with axis moving systems, calculations, results comparisons of both versions of solar panels, with normal stand and with a stand which can rotate panel.

This thesis aims to demonstrate that green energy including solar panels developed a lot since it was opened and that everyone can get it in case to ensure electricity stability for their own houses and families. Also, rising gas and electricity prices played its role of choosing this topic and it seems more than actual and needed nowadays to show people what they can get out of renewable energy technologies.

Figure 1. Solar panels on the roof of the house (Euronews 2022)

2 What solar panels are

2.1 Photovoltaic effect

Solar panel is a panel consisting of solar cells which use photovoltaic effect to get electricity. Photovoltaic effect is a process where solar cells convert sunlight into electricity. For getting this effect we need 3 layers, usually It is silicon, phosphorous (negative charge) and boron (positive charge). Electricity generated with use of photons which strikes electrons from their atomic orbit. This electron released into electric field generated by solar cells directed pulled to directional current. Below you can see picture explaining on how this effect works (Figure 2) and it may look complicated but on practice that is easy electrical circuit which works all the time whilst sun is up. (Online Solar, LLC)

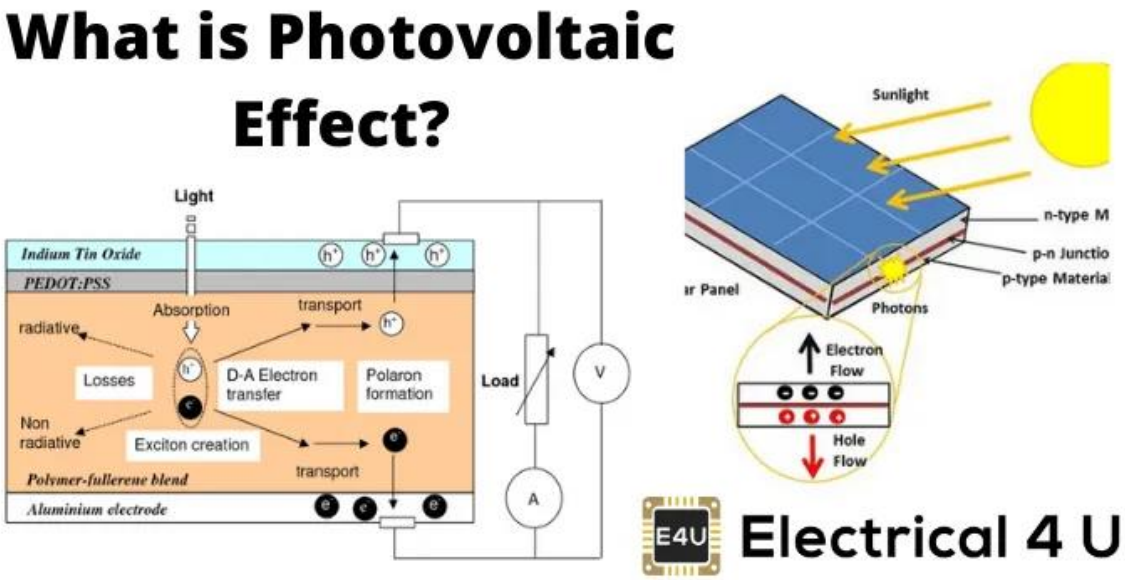

Figure 2 How Photovoltaic works (Electrical4U)

2.2 Parts of solar panel

Construction of solar panel has different elements which allows it to work in different conditions and if proper equipment used it can boost efficiency of the panel.

1. Solar cells

Solar cell (Figure 3) is one of the main parts in solar panel construction. It is the part that produces electricity with use of photovoltaic effect. made from n-type silicon layer, p-n junction, p-type silicon layer as can be seen on Figure 4. Silicon used as a material because it

is cheap, long lasting, and high efficiency. Also, there is 1 more thing which should be considered, and it is that lifetime After silico is used for 25 years, it still produces 80% of its maximum power. (U.S Department of energy)

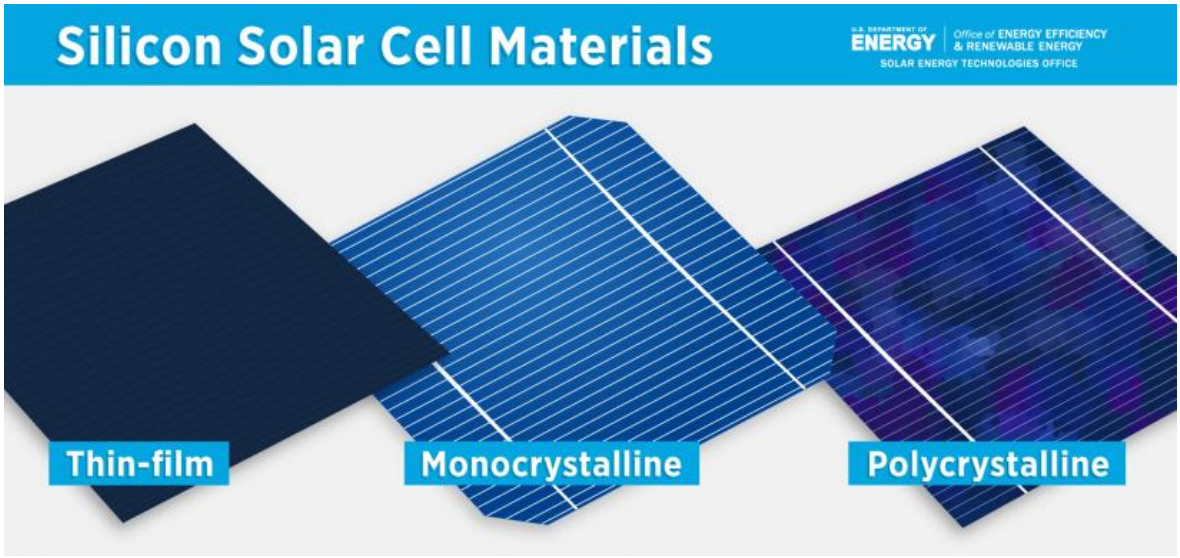

Figure 3 Solar cell (U.S Department of energy, 2022)

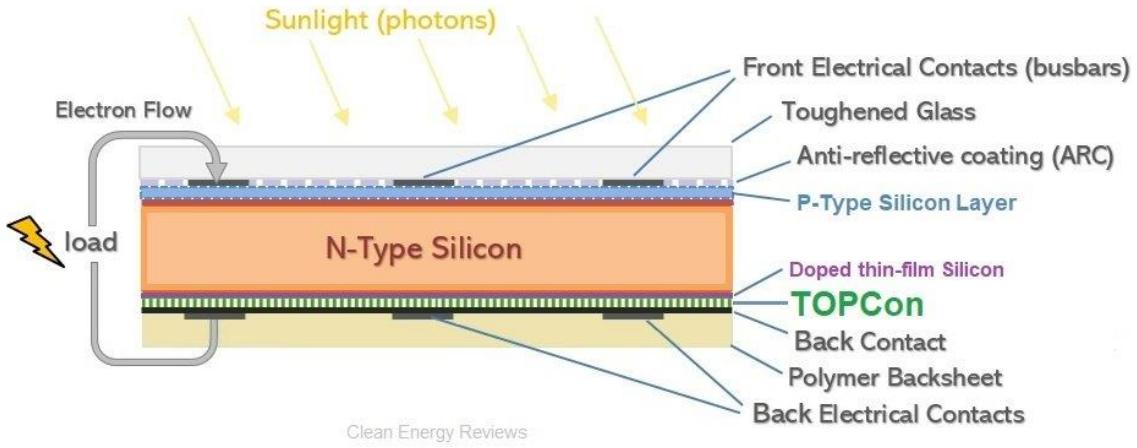

Figure 4 Components of solar cell (Clean energy reviews)

2.Tempered glass

In solar panels tempered glass used as a shield for solar cells, but it also has another possibility, examining some solar panels, may be found that use of tempered glass with an uneven surface (Figure 5) maximize the amount of sunlight they collect, leading to increased energy production. Of course, when it gets to the price, this type of glass it differs from usual tempered glass, but efficiency of the system should be considered in case to

maximize the power output of a solar panel, it is necessary to use the best materials for each component.

Due to its strong properties tempered glass is most useful type of glass for this application. It can withstand different weather conditions like storm or snow rain.

Figure 5 Tempered glass with uneven surface installed on solar panel (YouTube (a) 2019)

3.Frame.

Frame (Figure 6) used as a body of the solar panel, and it should be light and strong so it will not break under any circumstance. As a material there can be used aluminium. It has low weight and good corrosion resistance which needed in case where it has different weather conditions. About strength of aluminium there should be mentioned that mostly this construction will be strong since it has tempered glass and epoxy resin as a filling. These two added components will make body of solar panel strong enough to withstand any wind or snow rain for example.

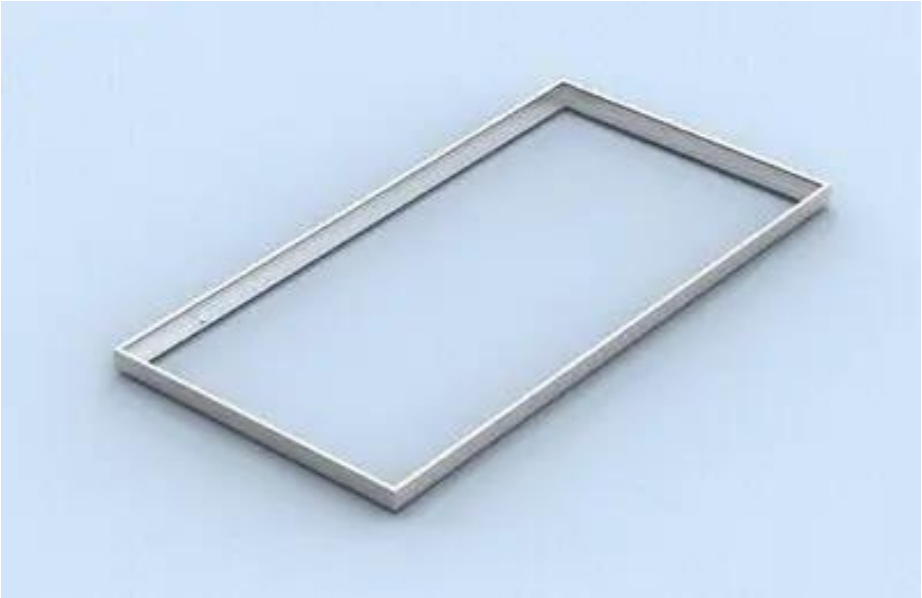

Figure 6 Aluminium solar panel frame (Wellste Aluminum 2022)

4. Rotating system

Not compulsory part but according to research papers it increases efficiency of solar panel up to 32% and makes the solar panel get each sun ray (BDG Media, Inc). There are few possibilities on how to get solar panel move: Hydraulic system, Pneumatic system, or electric motor with gears. In the next chapter can be found comparison between all these systems and justification of author's choice.

3 Comparison of systems

3.1 Introduction to analysis

For the first before starting development there needed analysis of systems which can be used for rotational system and pick most suitable for this case taking into an account specific weather conditions like temperature fluctuations or rainy fall for example.

There are few options on which systems can be used for moving: Hydraulic, pneumatic, motor and gears.

3.2 Advantages and disadvantages

Hydraulic system

In hydraulic system as can be seen used motor, pump, actuator, and other components (Figure 8) which make system work. Example which author is going to use does not relate to this picture and used just as a simple explanation for the reader. Everyone knows what is braking system in car and what it used for, but how does it work?

When driver pushes braking pedal it moves cylinder connected to pedal which creates pressure on braking pad fixed to braking disc on each wheel. (Alex Muir 2022)

This simple example (Figure 7) shows well how liquid can be used for making pressure and moving parts. (Learn Driving Tips)

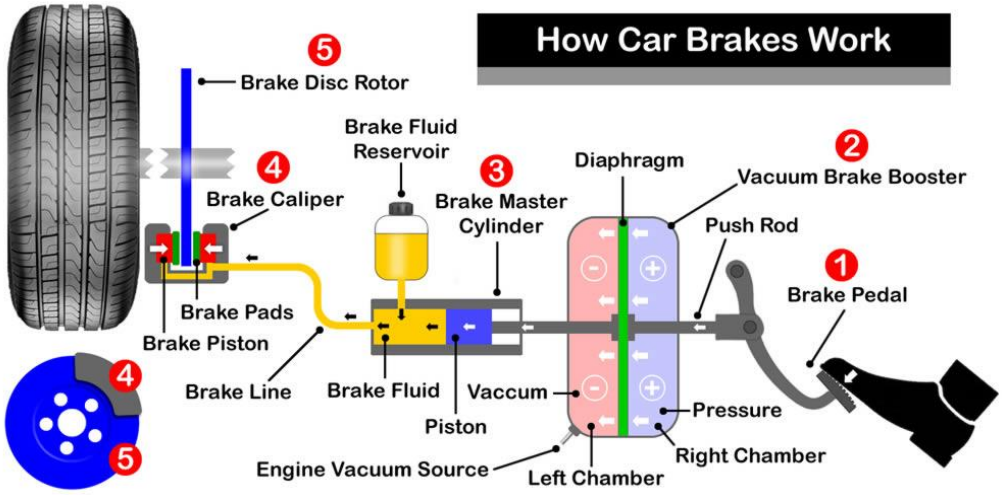

Figure 7 How car brakes work (Learn Driving Tips)

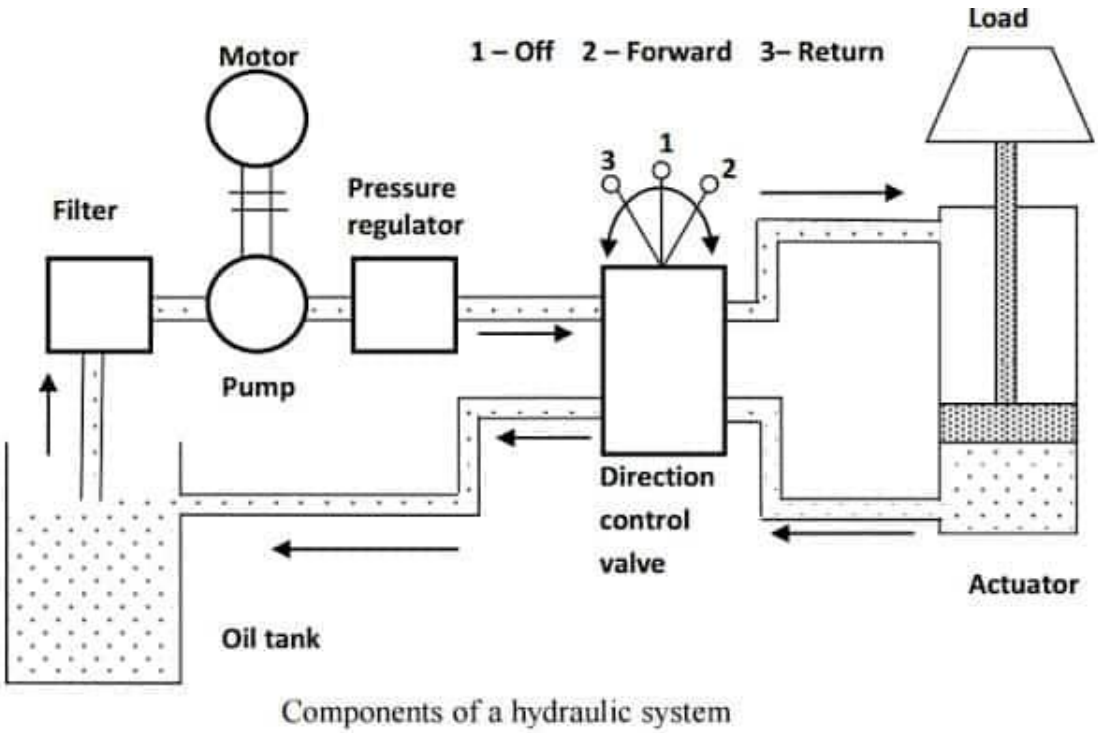

Figure 8 Hydraulic system components (Learn mechanical engineering)

Table 1 (Whyps, April 2, 2019)

Advantages	**Disadvantages**
Good force transmission	If leakage happens it harmful and dangerous for an environment
Self-lubricating system	proper maintenance needed to avoid damage of the part
Easy to control	needed good filtration system

Pneumatic system

Pneumatic system-engineering system which use mostly compressed air or gases to move cylinder. It works exactly like hydraulic system works with only one difference, in pneumatic system (Figure 9) used gases instead of oil which have its own advantage comparing to hydraulic system. (Norgren Ltd.)

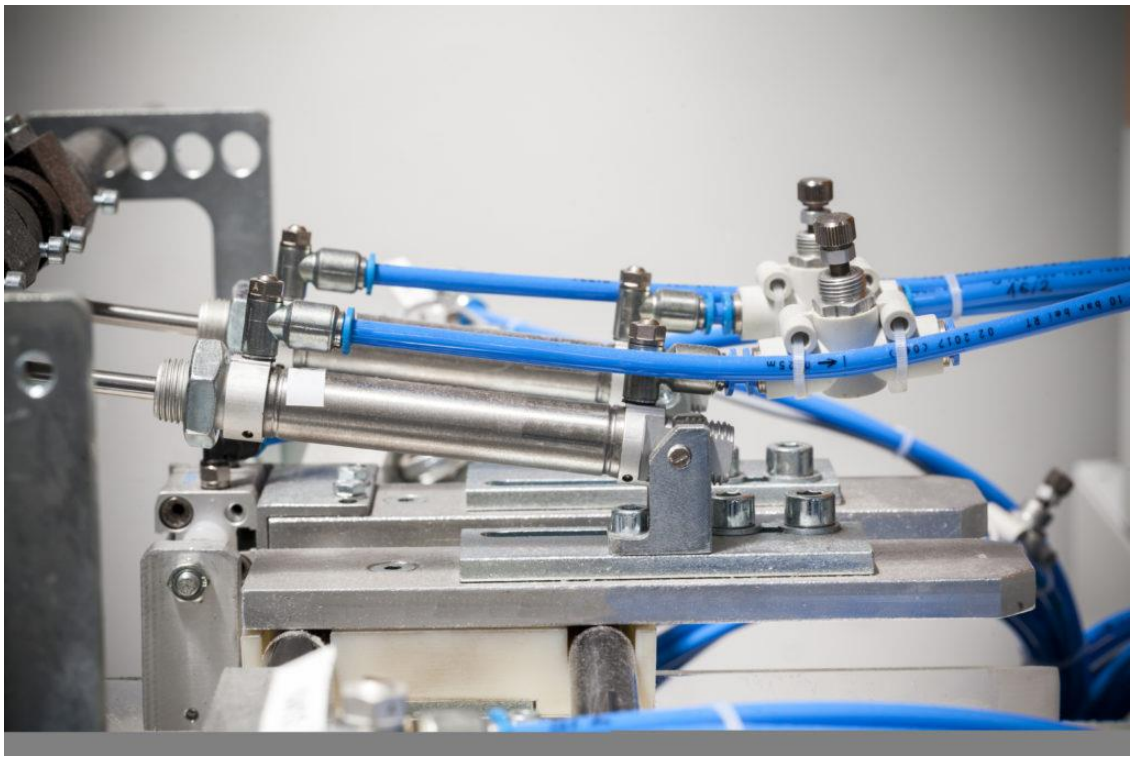

Figure 9 Pneumatic system (Global Electronic Services)

Table 2 (Interclass 2012)

Advantages	**Disadvantages**
Filling used in system is air	Needs air producing machine
Easy to provide from point A to B	Filtration system is important to avoid moisture in cylinders
Not depend on temperature and safe	Easy to leak

Below (Figure 10) you can see main components of pneumatic system and as can be seen this system requires a lot of different components like valves compressor switches etc.

For axial moving system it may be quite complicated to use such a system since it may take a lot of space or energy since there will be a need to produce extra parts in case that we have to ensure all our system are fixed properly.

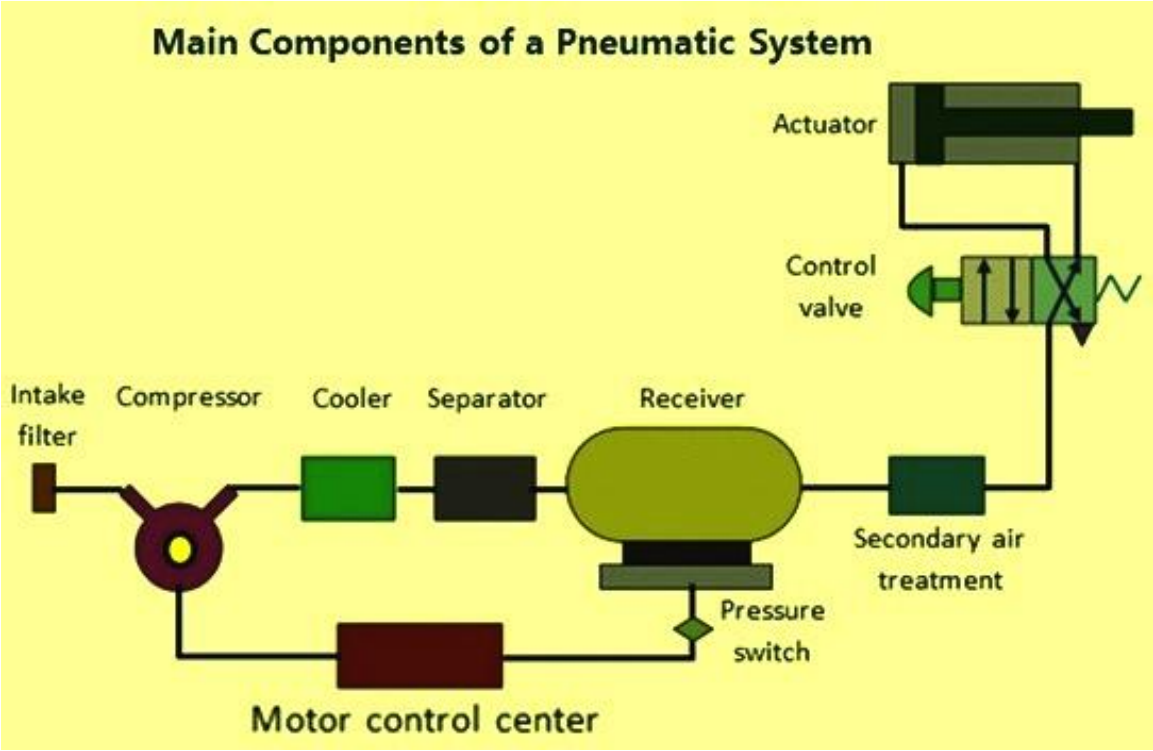

Figure 10 Pneumatic system components (Ispatguru 2019)

Motor and gears system

There is no needed deep explanation on how motor and gear system work, briefly motor rotate gear which connected to another gear and while motor rotate one gear, that gear transfer torque to another gear.

Table 3

Advantages	**Disadvantages**
depending on specific use can use electric-ity generated from solar panel	Proper material choice should be used to avoid stuck of gears in case if it gets too cold
Low power consumption due to low rotation speed (Approximately 15 degrees/hour horizontal axis)	Chance of short circuit which can lead to fire.

3.3 Analysis

3.3.1 Pros and cons comparison

According to pros and cons of all 3 systems it makes some sense to say that third system which include motor and gears looks most relevant system for solar panel axial system due to its easiness of use and low power consumption compared to another system which needs extra equipment like pump or air compressor. Also, there is big advantage when we talk about on how precise system can be with gear system it is way much easier to calculate position due to gear ratio and rotation speed. If we talk about replacement of parts, it of course depends on a design of specific system but anyway for gear system not needed pipes and other parts which we need for transporting liquids or air, power transmission works straight from motor to gear.

Approximate average power output of usual solar panel differs and mostly affected by shades, hours of sunlight and orientation of the sun (EnergySage 2022). Since our panel will face sun all the possible time it means that last mentioned impact can be excluded from the list. According to the Energysage website panels can produce 0.3kWh+ and it means that while regular day when we have sun it can produce if minimal output of 300W:

$$Output = 300W * 8\,hrs(Sunlight\ time) = 2400Wh = 2.4kWh$$

Of course, since sunlight time vary results can be different from shown ones, mainly it was presented to show how much it can make during day. For actual calculations should be taken real values for exact used solar panel.

3.3.2 Price and complexity of system

If we talk about complexity of the needed developed system, it is easier and cheaper to develop system which use electric motor compared to other systems. Its needs less components which cheaper than other ones.

For justification a table will be presented to show difference in price and number of needed components. To make it equal values for table will be taken only for simplest cases.

System with electric motor has electric motor (1), small battery (2), relays (3) since motor is going to be turned on with power going from solar panel so we can control that first battery is going to be charged and then it turns on second circuit which transfer power to inverter and after to consumer.

For the system with use of hydraulic components we need motor (1), pump (2), filter (3), pressure regulator (4), oil tank (5), load (6), actuator (7), direction control valve (8). (Learn Mechanical Engineering)

And pneumatic system needs intake filter (1), compressor (2), cooler (3), separator (4), dryer (5), receiver tank (6), control valve (7). (Hydrastar Ltd.)

Note: It was hard to find prices for those systems since they used mostly in commercial systems which needs high power and since this study focus on development of axial moving systems represented prices shown is approximate. For pneumatic and hydraulics system prices taken for smallest workable solutions

Table 4

	Electric motor and gears	Pneumatic	Hydraulic
Price	80 euros	200-300 euros	500 euros
Number of components in system	3	8	7

3.4 Possible light sensors solutions

Light sensor is a sensor which measures incident angle of sun ray and allow program to get information about on where sun located. After program gets information, it moves solar panel so angle between panel and sun ray equal to 0 which means that solar panel get as much sun as possible. (Solar MEMS Technologies S.L. 2022)

There are few practical solutions for light sensors for solar panel:

- Use advanced part (expensive and precise) (Figure 11)
- Simple part consisting of 2 small solar cells with wall splitting 2 solar panels (Cheap and not that much precise)

Advanced sun ray tracker has high precision and small tolerance, but it increases cost of overall system which means that this solution should also include program and special equipment for realisation.

Figure 11 Advanced sun ray tracker (Solar MEMS Technologies S.L. 2022)

On the other side cheap solution like shown in Figure 12 which is not that expensive, but it has higher tolerance and lower precision which does not meet our requirements for high precision and low cost

Figure 12 Possible handmade sun ray tracker solution (YouTube (b))

Alternative solution for light sensor can be program which calculate angle and position of the sun at exact time. Technically can be found online and uploaded to a controller. Biggest advantage of this solution that for use of this solution user only need microcontroller and working pc. In this case user pays only for controller and it looks like best solution for our case since it cheap, precise, and only need manual calibration of position.

3.5 Recyclability of the various parts of solar panel

Currently in time we live recyclability and green energy plays huge roles in our life. Every day we see recycling trashes where different material is sorted and assigned to separate boxes and according to this it makes sense to check recyclability and sustainability of the materials which used in solar panel production so in future materials from this can be used again and there is no harness done to an environment.

For comparison and justification there will be used table to visualise and see how good or not each part. Below can be found table with analysis for solar panel components.

Table 5

Part	Material	Recyclability	Sustainability
Solar cell	Silicon and metal	Yes	Not best for silicon
Frame	Aluminium	Yes	Sustainable material
Encapsulant	Epoxy resin	No	Not sustainable
Tempered glass	Silica, Calcium carbonate and sodium carbonate	Yes	Yes

Talking about first mentioned element of solar panel solar cell it consists of silicon and metal mainly and if we talk about these two materials separately there should be mentioned that for metal, we know that it can be easily recycled and it is sustainable material, not all the metals sustainable but in solar cell used few types of metals

- Zinc oxide – used in newest photovoltaic technology for its great energy conversation. (Figure 15)
- Copper - good conductivity, used in wiring. (Figure 13)
- Silver-Excellent conductivity, Used in wiring too. (Figure 14)

Figure 13 Copper

Figure 14 Silver

Figure 15 Zinc oxide

From all these 3 metals there is no unrecyclable material and all of them sustainable as much as it possible which means it does not impact environment a lot or do not affect at all (NSW Government)

For the second part metal frame used material is aluminium which recyclable and environmentally sustainable. (The Aluminum Association, 2021)

When we talk about encapsulant there should be mentioned that epoxy resin is not recyclable material, and it is not most environmentally friendly material but there are no alternatives for this.

Proceeding to the next element used in solar panels glass (Figure 16) there can be told that as almost usual glass it can be recycled but since there extra elements it should be reviewed more. extra elements which make usual glass tempered is calcium carbonate and sodium carbonate. Mostly calcium carbonate (Figure 17) is natural components which can be recycled. When we talk about sodium carbonate it is natural part too and can be recycled as well as calcium (SHC Group Company, 2022)

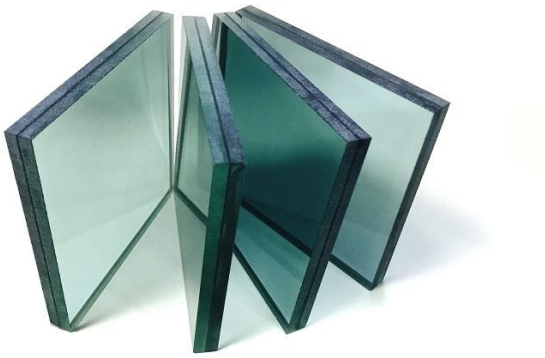

Figure 16 Tempered glass (Asahi India Glass Limited, 2022)

Figure 17 Calcium carbonate

4 Development of the 3D model

4.1 Description of what model should include

Since technology for the solar panel had been chosen it make some sense to discuss on what should model include for the best performance:

- Stand where we place our solar panel
- Mounting frame for the solar panel
- gear with key slot for providing axial movement
- another part which is not actually gear but it is used as a gear

For the best performance we should have gears connected separately from each other on various parts in case to avoid collision.

4.2 Engineering specification

Geometry		Values
Weight of construction	W	25-30kg
Size of the panel (60 solar cells)	D	60 solar cells
Overall height	D	1.5m
Easy installation to base	W	<60min
Easy replacement of the motors	W	
Kinematic		
Speed of moving	D	15 degrees/hour
Manual control	W	
Low electricity consumption by motor	W	

Figure 18 Engineering specification table

For this case there should be considered on how fast sun moves over horizon in 1 hour to do all the gears for motor and solar panel stand moving as precisely as possible in case to make our system facing sun as much as possible.

4.3 Idea on how axial movement can be realised and what should be considered

Since we use electric motor and gears to move solar panel it make 3D modelling and development harder since for x-z movement up and down should be developed from scratch.

Usually when using other 2 systems there was cylinder attached to solar panel and moving it up and down as can be seen on Figure 19.

Figure 19 Solar panel moving stand with use of pneumatic system (Off Grid World, 2022)

System like that has it is own disadvantages like angle limitations on how much it can move left right and up down.

Taking it into account there is 6 main goals to be considered while prototyping new system.

1. Model X-Y system
2. Model X-Z system
3. There should not be any interference between these 2 systems
4. Proper material selection for each part according to its role and acting forces.
5. Minimize overall weight as much as possible in case to make possible easy transportation of the system
6. Use less fasteners in case to reduce assembly time

All those steps should be considered in case to make construction stable and well working.

4.4 Finished Prototype review

On the Figure 20 and Figure 21 you can see completed prototype of solar panel and above picture will be analyse of the system, its functions etc.

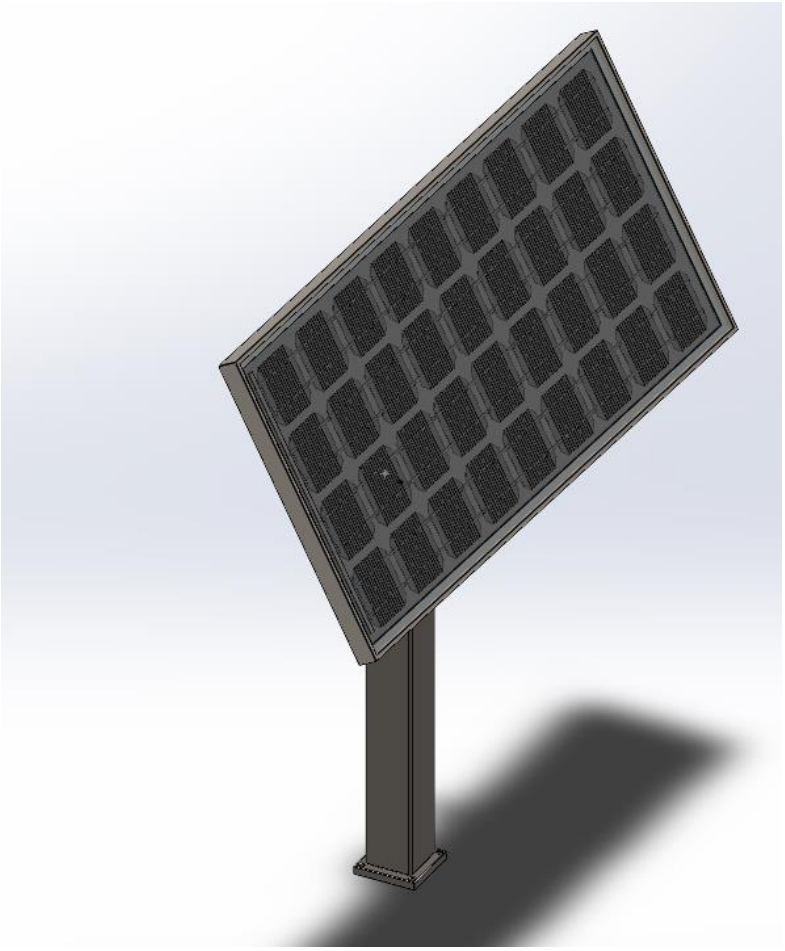

Figure 20 Front view of prototype

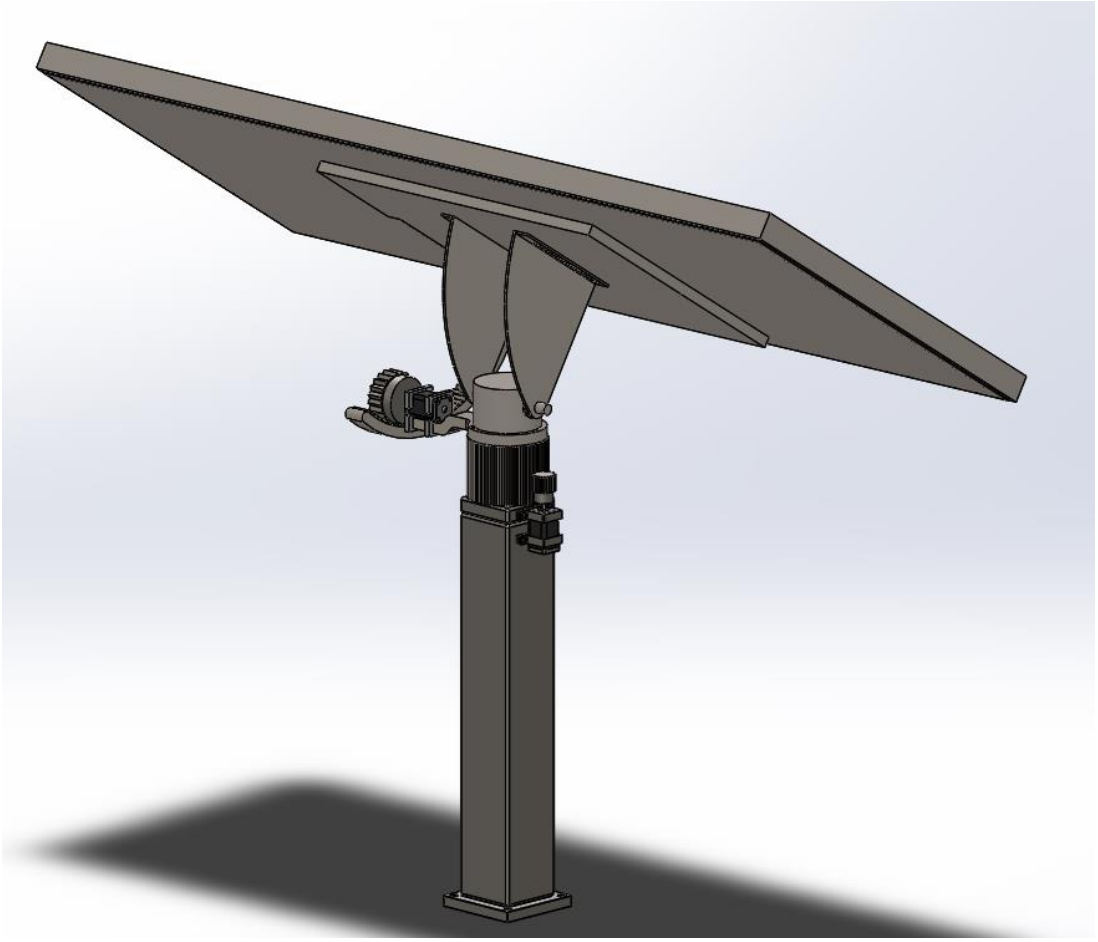

Figure 21 Rear view of prototype

After prototype has been shown it makes some sense to mention that solar panel itself have not been developed by author, instead of this it has been taken from GrabCad website library (GrabCad, 2022. Eslam Helmy November 2, 2022) just as a representation of how definitive version might look. On the Figure 22 can be seen closer look at developed rotational mechanism.

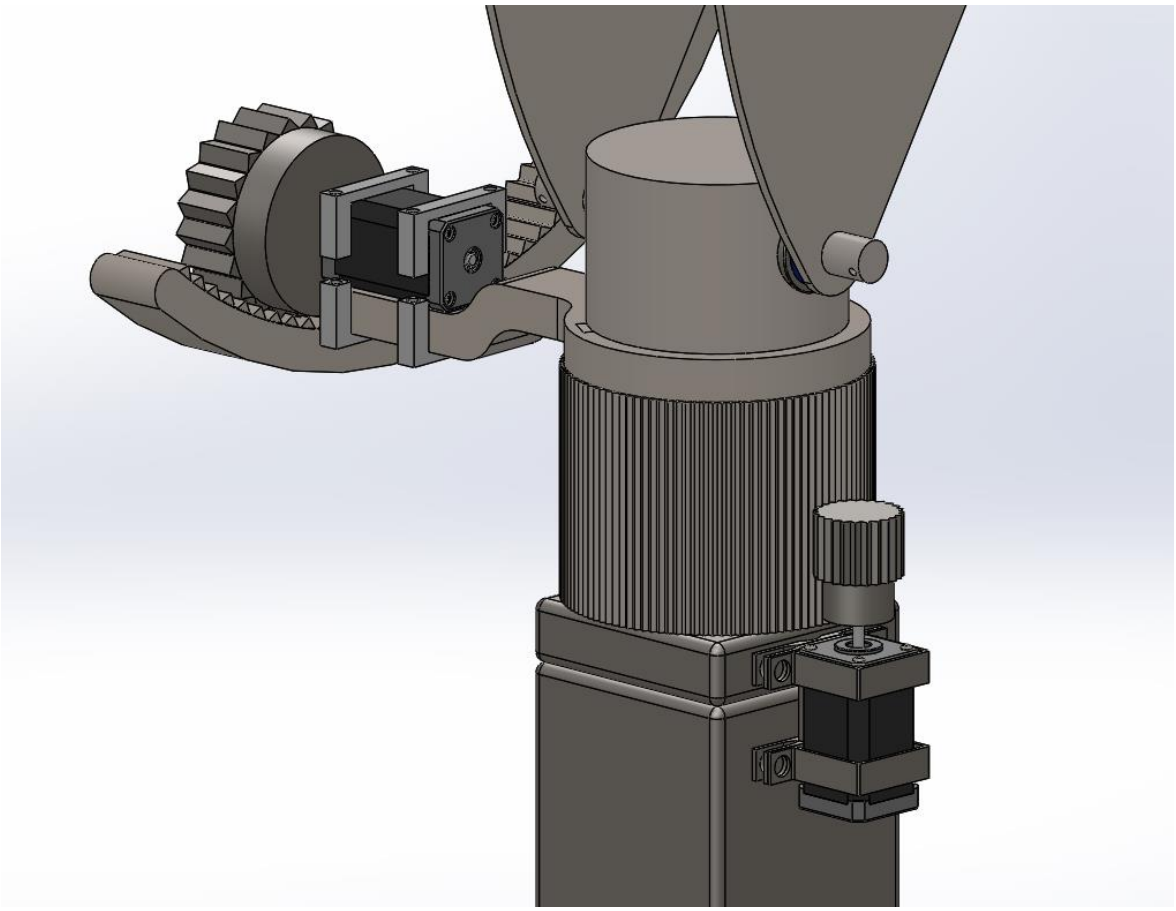

Figure 22 closer view of rotational mechanism

In this construction used 3 gears and 2 motors. Most challenging thing was to make synchronization of upper gear attached to upper motor with lower gear which rotate upper parts so upper gear will not stay at one place and rotate with solar panel. So that was the first problem to be realized as we go from up to down and solution for that is mount fixed on rotational gear with key slot (Figure 23).

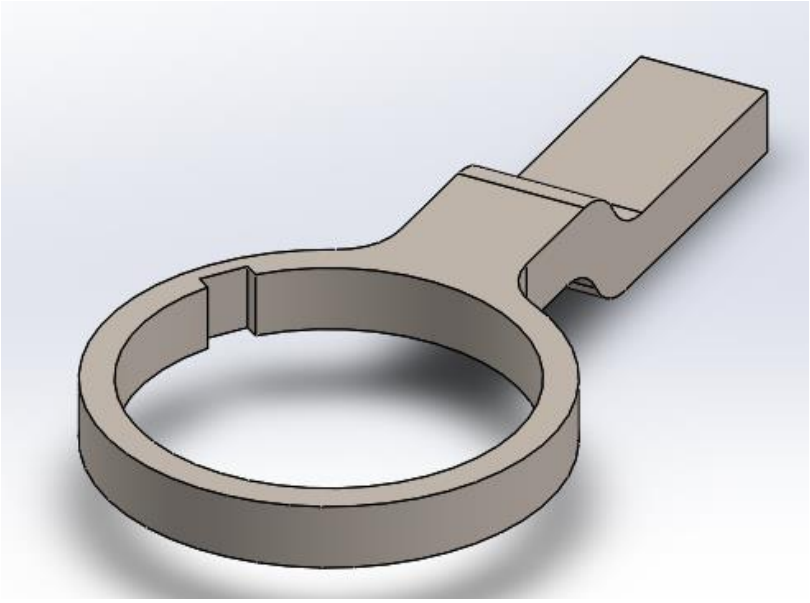

Figure 23 Mount for motor with key slot

It allows to attach motor on top and fix it with special holder. There is no high torque, so it does not need thick walls around hole with key slot.

Next important part is gear attached to solar panel frame which make movement of the frame along X-Z axis (Figure 24)

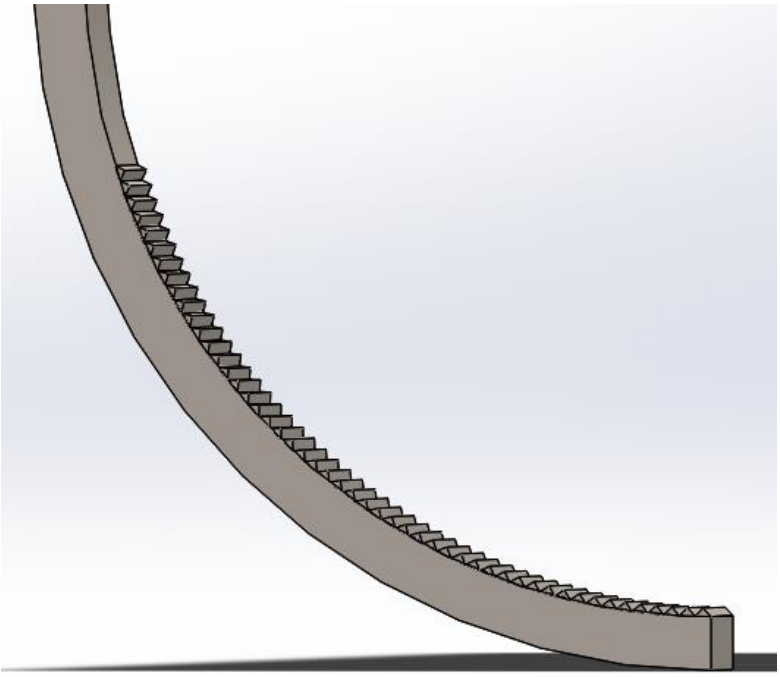

Figure 24 X-Z axis gear

Since our requirements for both gears to be able to move approximately 15 degrees/hour makes possible to use smaller teeth since force on this gear is not that big as panel weight so on both gears approximate height for each tooth is 3-5mm.

Next element is lower gear (Figure 25 and Figure 26) which move along X-Y axis, and it has few roles, first one is gear option and another one is that it works as a stand for solar panel frame and mount for motor which represented in Figure 22.

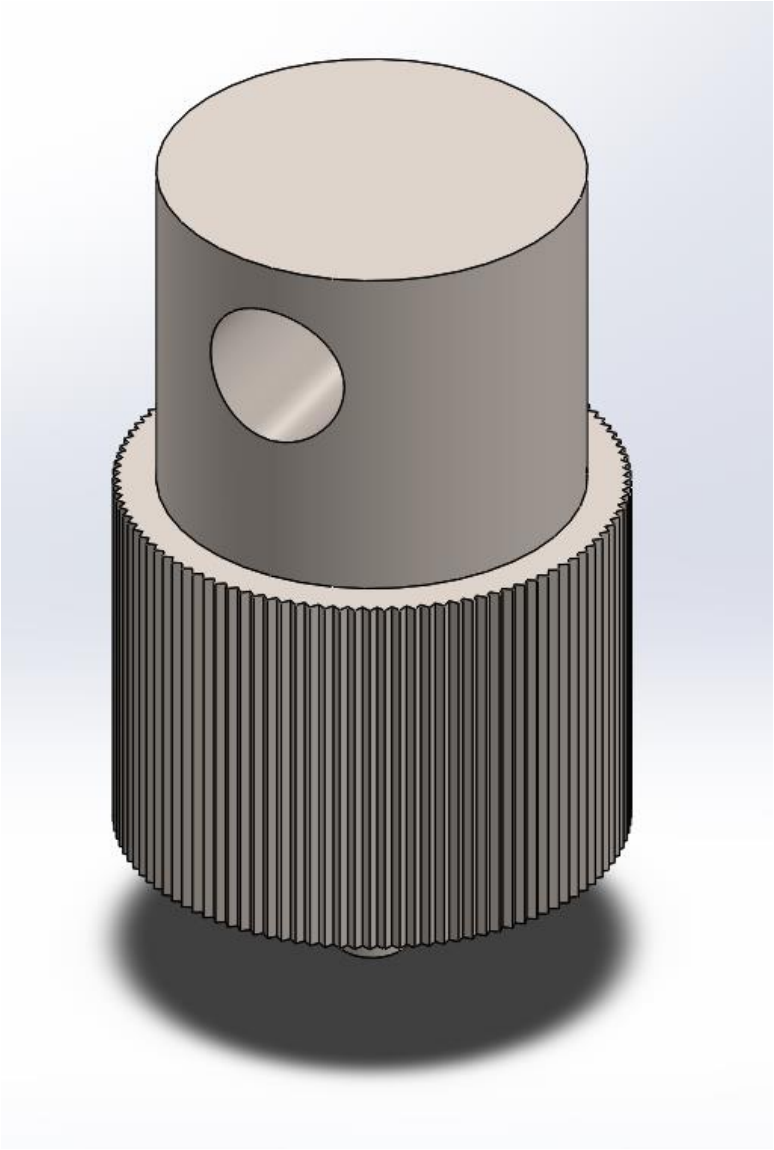

Figure 25 Lower gear isometric view

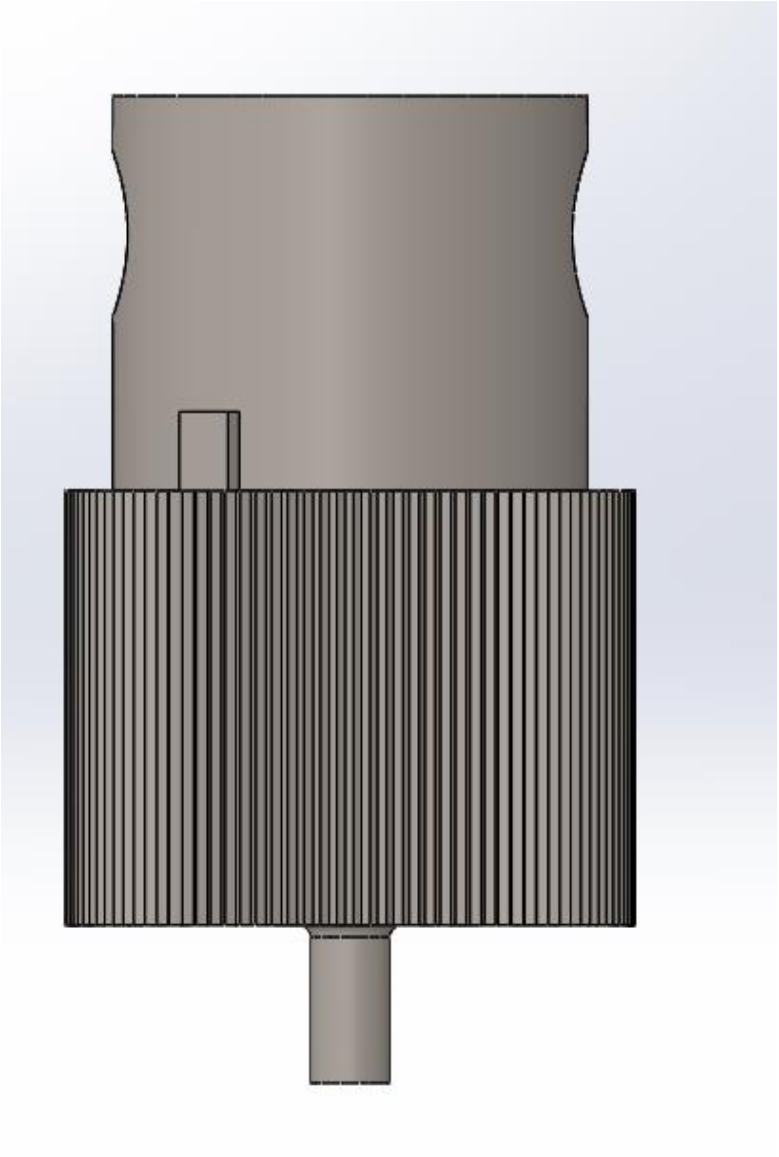

Figure 26 Lower gear side view

Since it also works as a stand it makes sense to mention that this part technically should have strong body in case that it should be able to receive high torque from motor and with-stand high weight of solar panel (Approximate force acting on this part is 30-40kg including motor and solar panel mounting parts). For connecting lower gear with stand base used slide bearings (D&E Bearings), one with flange and another one without flange and you can see how It look on Figure 27. Mainly this design was chosen to avoid any problems related to mass handling so it will not break while wind or harm weather conditions.

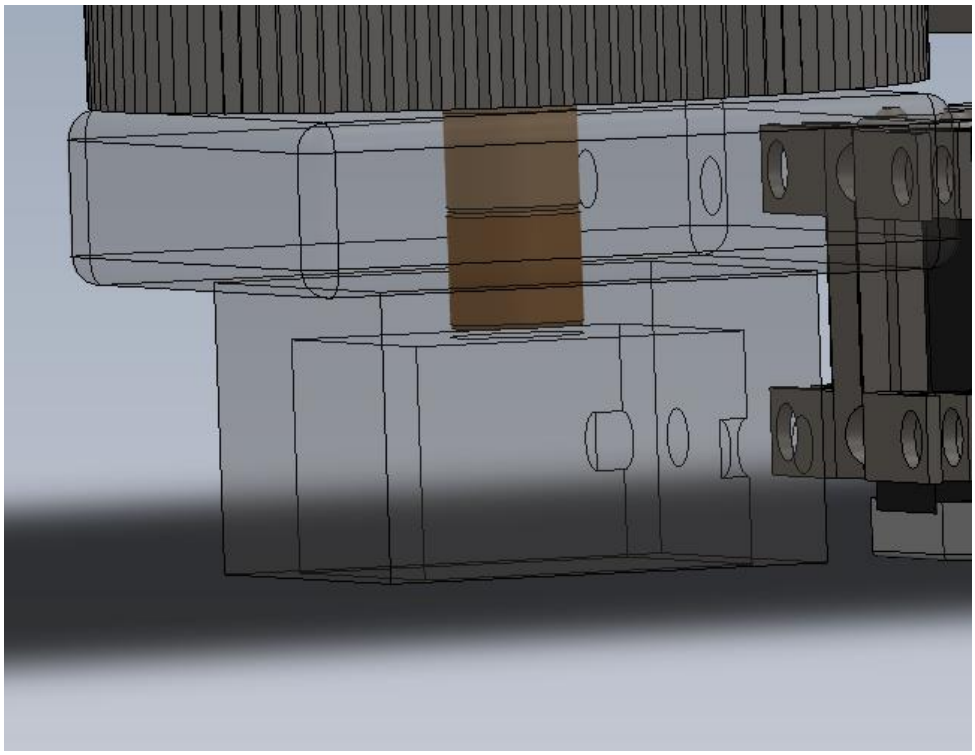

Figure 27 Slide bearing connection

That was key parts of rotational mechanism and after it was shown there should be calculations to justify on what torque should have our motors and FEM simulation for holding parts.

4.5 Calculations and strength simulation

All the calculations shown below are simplified, it is done that way since there is no exact values for the masses and mostly all the taken values are approximate, also there cannot be predicted how different weather conditions affect our gears and movement so picked motor will be more powerful than needed.

For calculations of the motor power should be known torque. Torque is a measure of a rotational force on the object and has formula T=r*F, where r is distance from point of rotation to the point where force applied, and F is applied force. (University of Guelph, 2022).

As an Applied force where will be taken mass applied to a body which are going to be rotated multiplied by g=9.8$\frac{m}{s^2}$. After that distance r should be found which equal to gear radius.

Defining forces applied to the gear there will be taken maximum force for gear rotating in X-Z axis (Figure 24) and for the lower gear (Figure 25) will be used usual mass.

Upper motor torque and motor power calculations

For the upper motor as a mass should be taken mass of the solar panel frame and solar panel. Solar panel mass is approximately 30kg and for the frame according to mass evaluation feature approximately 15 kg. In total mass gets to 45kg and acting force can be calculated with use of formula shown before:

$$F_1 = m_1 \cdot g = 45kg \cdot 9.81\frac{m}{s^2} = 441.45N$$

First torque equal to:

$$t_1 = F_1 \cdot r_1 = 441.45N \cdot 0.084m = 18.49\ N * m$$

To calculate power, needed torque and angular velocity, since approximate value for angular velocity known (Approximately 15 degrees/hour) and torque equal 37 N*m the only thing that should be done before calculating power is to convert angular velocity from 'degrees/hour' to 'rad/s

$$v = \frac{(\pi \cdot 15\frac{degrees}{h})}{180} \cdot \frac{1}{3600} = 0.087\frac{rad}{s}$$

So, after those final calculations for the motor will look next:

$$P = 18.49 \cdot 0.087 = 1.61\ W$$

For that case it seems that there is no need in big motor and compact one can be used since it does not need a lot of power. On the Figure 28 can be seen example on how motor can look. There was picked 10W motor since in calculations have not been calculated different unexpected conditions, so it is why power of the motor larger than needed. Also, it is not shown on the final 3D model but there should be used cover for the motors so it will not get dirty, and it will work properly.

Figure 28 10W Servo motor (Distrelec Schweiz AG, 2022)

Lower motor torque and motor power calculations

For the next calculations it is only needed to change mass and radius (Radius of lower gear equal 16mm (0.016m) in all these formulas and then result is needed power for lower motor which rotate lower gear shown on Figure 25. Mass on the lower gear increase by approximately 15kg and it means that mass equal to 60kg and calculations for it:

$$F_2 = m_2 \cdot g = 50\ kg \cdot 9.81\ \frac{m}{s^2} = 490.5\ N$$

$$t_2 = F_2 \cdot r_2 = 588\ N \cdot 0.016\ m = 7.89.4\ N * m$$

$$v = \frac{(\pi \cdot 15\ \frac{degrees}{h})}{180} \cdot \frac{1}{3600} = 0.087\ \frac{rad}{s}$$

$$P = 7.8 \cdot 0.087 = 0.67\ W$$

For this case the same motor can be used as in previous case.

FEM Simulation for the most critical elements

After calculations done should be completed simulation for critical parts which have most load, those critical parts shown in Figure 29.

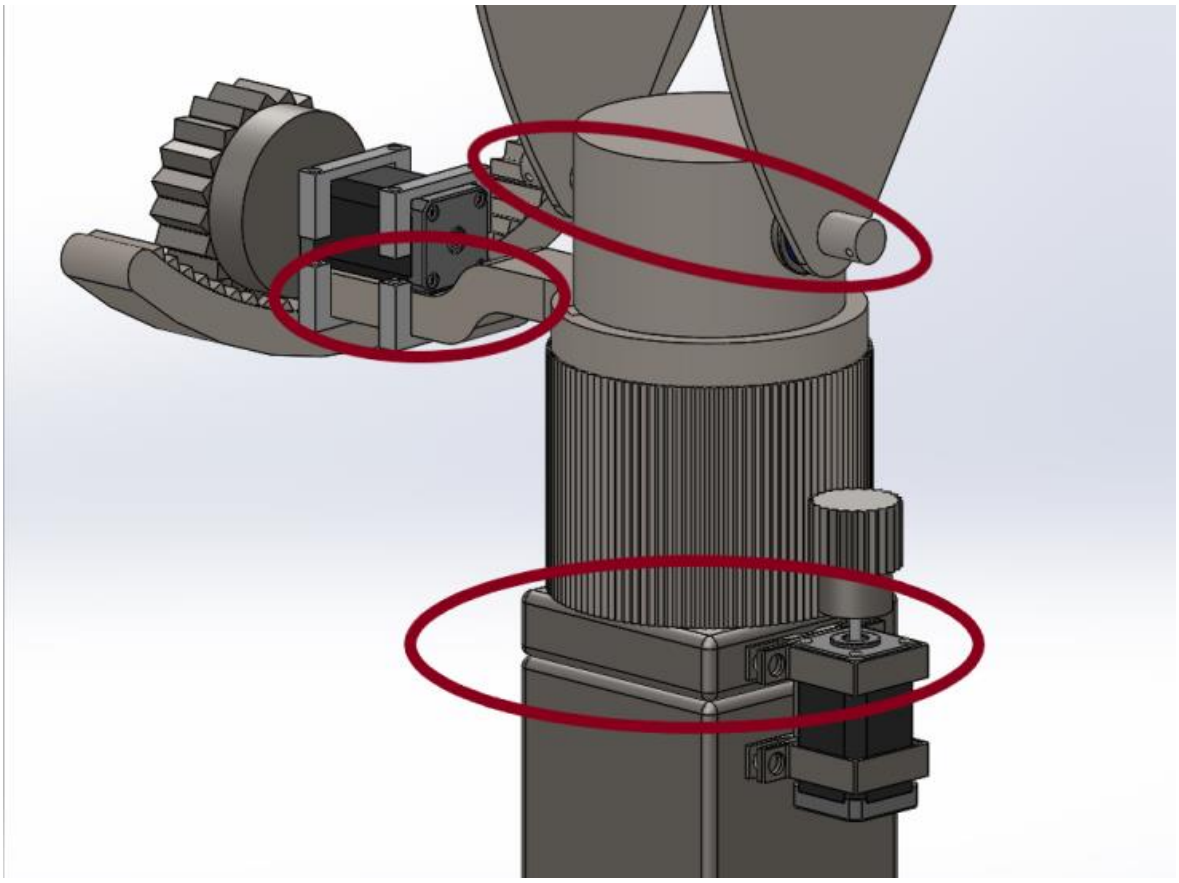

Figure 29 Critical parts to be tested

First part (Stand base)

For the first simulation with most critical part, stand base, it needs extra calculation since force acting on stand located not exactly at the top of stand base. How force acts and its direction with dimensions can be seen on Figure 30. Mass taken for this case was equal 50 kg. It includes solar panel, frame, and movement mechanism with motors.

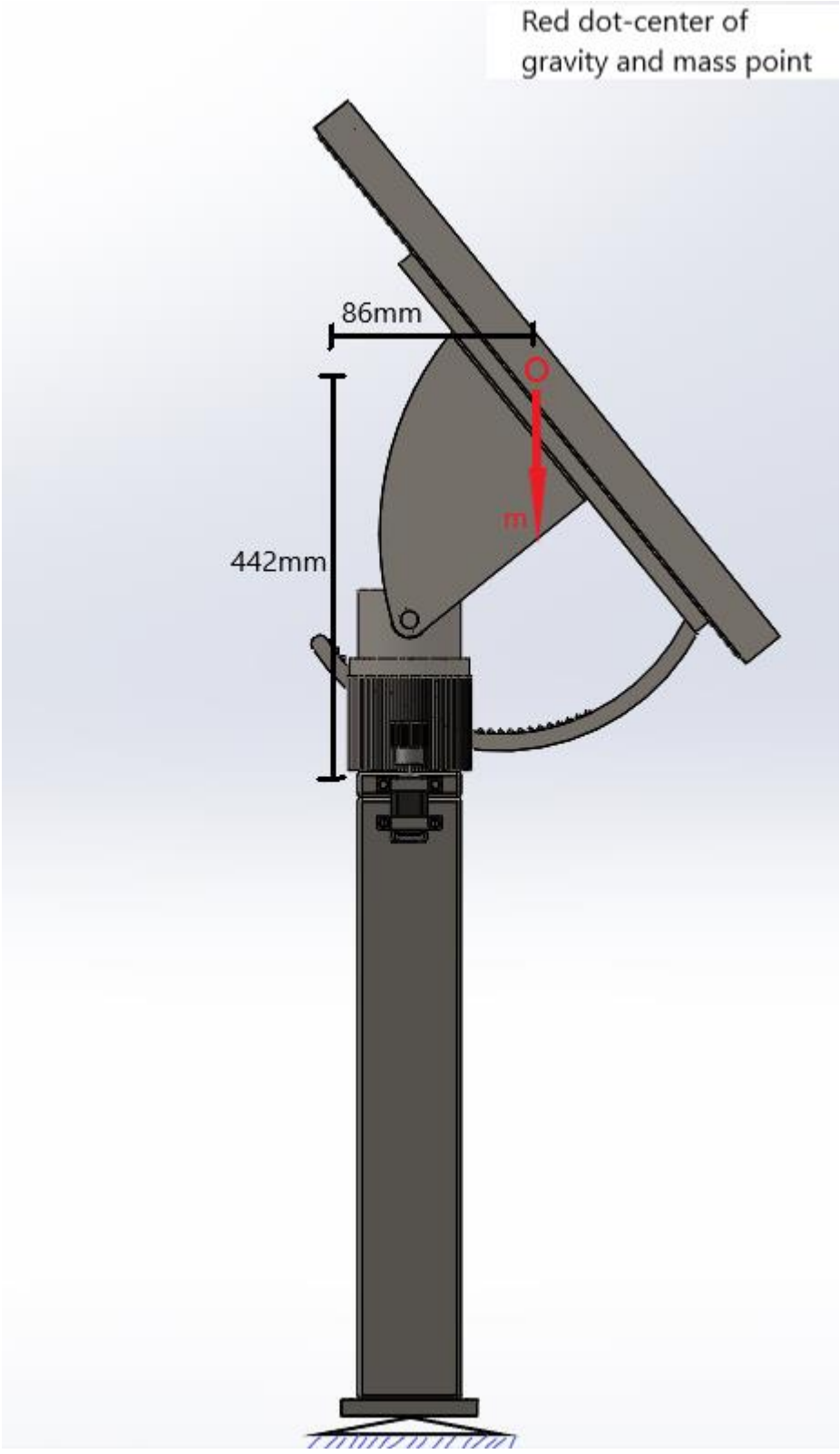

Figure 30 Free body diagram of stand base

On the Figure 31 can be seen final simulation, where force located at and how it acts, also there located force acting from right to left which is representation on how wind load simulation was realised with use of SolidWorks feature called remote load which used to set up force acting not straight to face of the model.

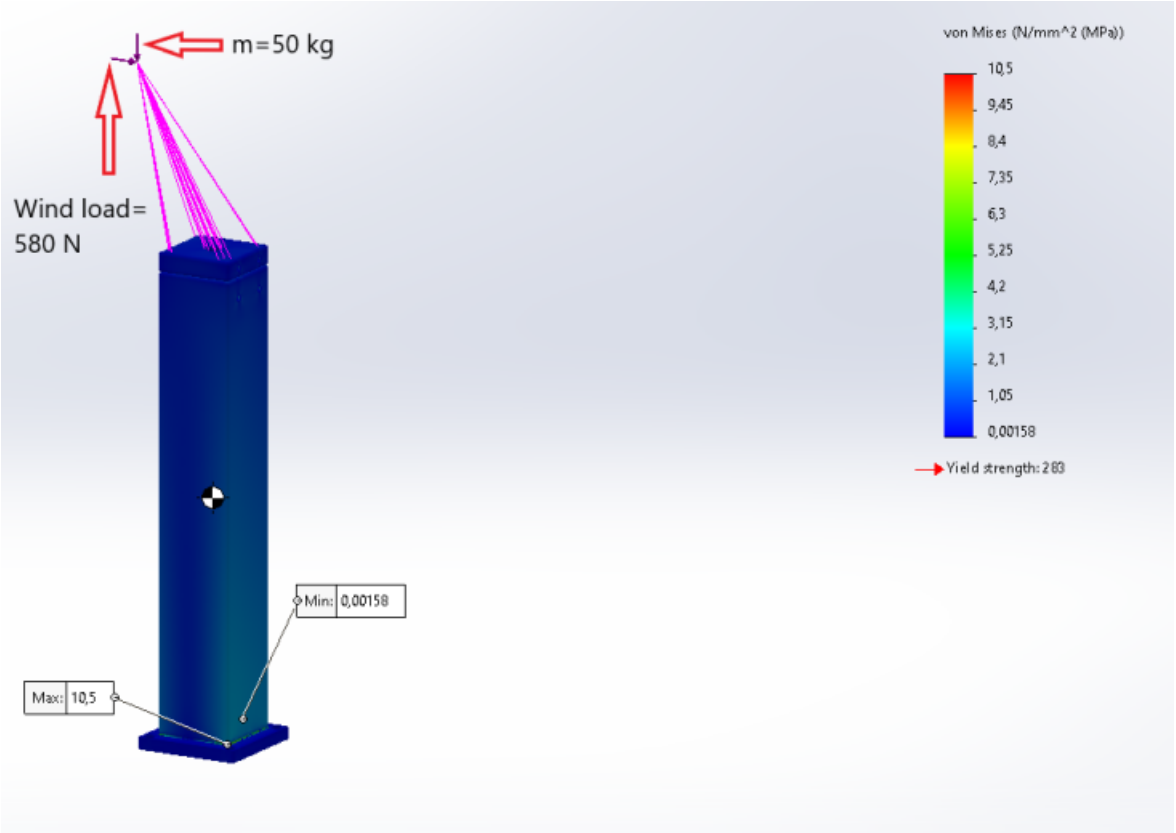

Figure 31 Simulation for the stand base. (Von Mises)

As can be seen acting force not biggest one and Solar panel stand will withstand solar panel itself and for this simulation was applied storm wind load which has speed of 119 km/h and with solar panel surface area of 1.26 m^2 it produces approximately 580N according to online wind calculator website 'Omni Calculator'. (Omni Calculator sp. z o.o.). Formula used for the calculations represented below.

$$F = 0.5 * Air\ density\left(Usually\ it\ is\ 1.225\ \frac{kg}{m^3}\right) * wind\ speed^2 * total\ surface * \sin(angle)$$

Also, Displacement (Figure 32) should be checked for this case since it plays huge role that panel can withstand stormy weather and not displace so much from its initial position. And as can be seen maximum displacement equal to 0.0422 mm what means that model is proper, and it will withstand normal conditions where it has only weight of panel and external conditions like storm wind.

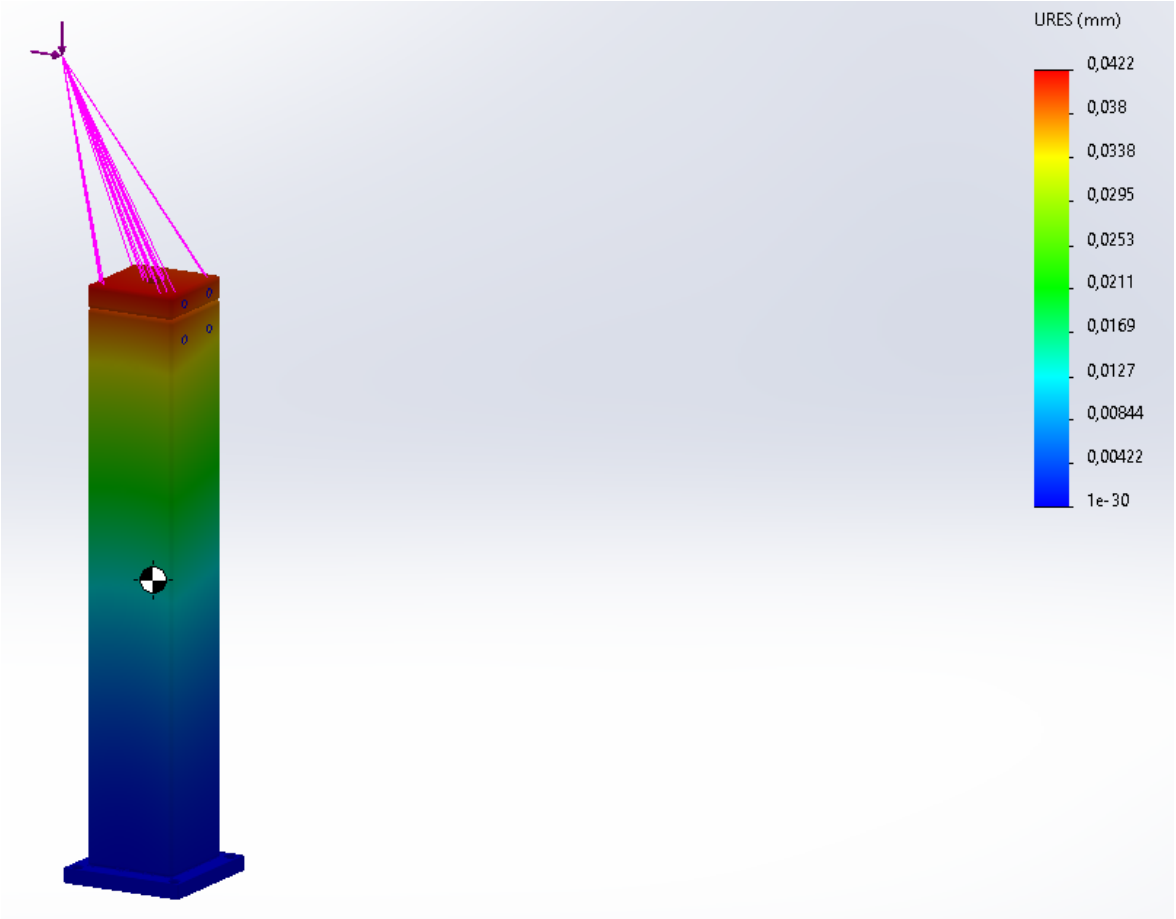

Figure 32 Displacement simulation for stand base

Upper motor holder

As can be seen on free body diagram on the Figure 33 we have force F acting on motor holder, since motor weights approximately equal 1 kg what means that acting force equal to

$$F = m \cdot g = 1kg \cdot 9.81\frac{m}{s^2} = 9.81\ N$$

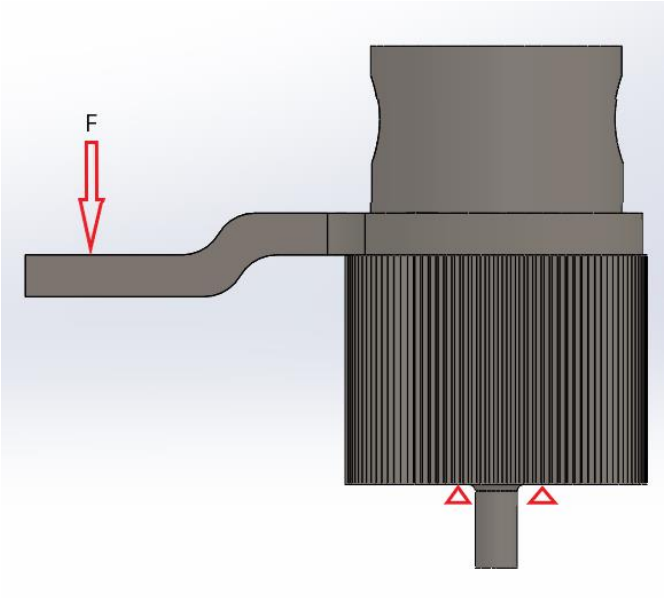

Figure 33 Lower gear free body diagram

Below can be found simulation (Figure 34) for the upper motor holder fixed on lower gear and it seems that since there is only used force which shows how motor acts on that holder but there should be considered also that motor with attached gear also lies on the upper gear, and it reduces pressure on that part. According to those results and factors this part can withstand needed amount of force.

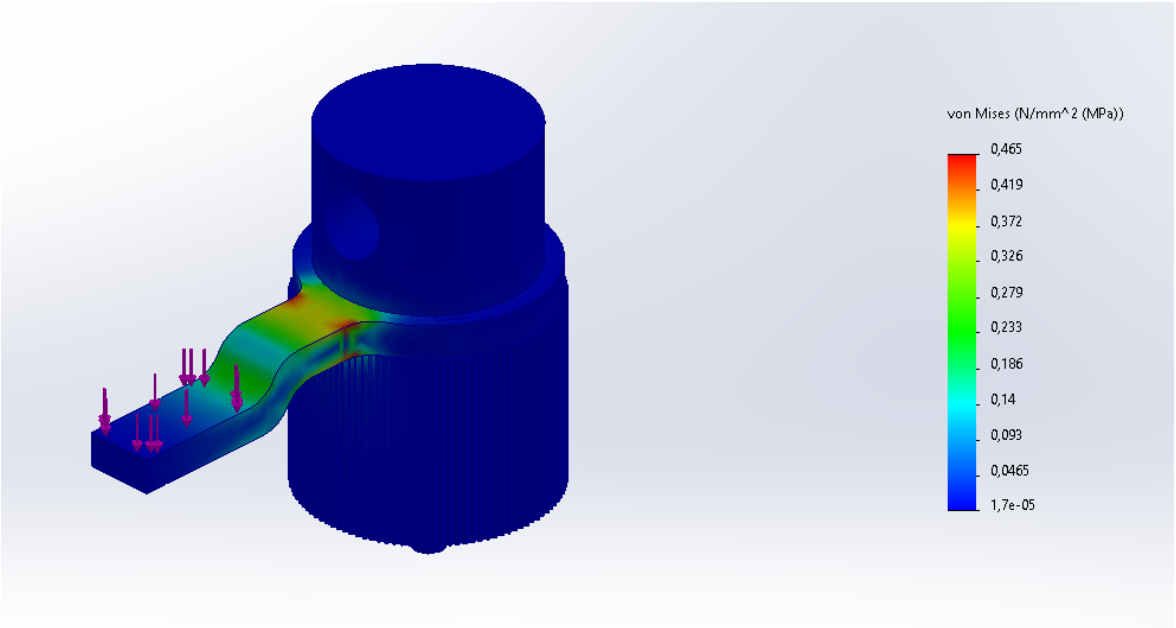

Figure 34 Simulation for the Motor holder

As can be seen final acting force is quite small and since it is only maximum 0.465 N/mm^2 there can be said that this part will withstand acting force and it also can be remodelled so it can be made thinner and with use of less material comparing to the first version.

Pin connecting solar panel frame with solar panel stand

Next most critical part is pin connected to lower gear which holds solar panel with its parts. On the figure 35 can be seen Free body diagram how force applied to this part.

Figure 35 Pin Free body diagram

Force applied to pin equal to weight of solar panel and frame with X-Z axis rotation gear (Figure 24). Below can be seen final simulation (Figure 36) with applied force equal to mass of solar panel with frame.

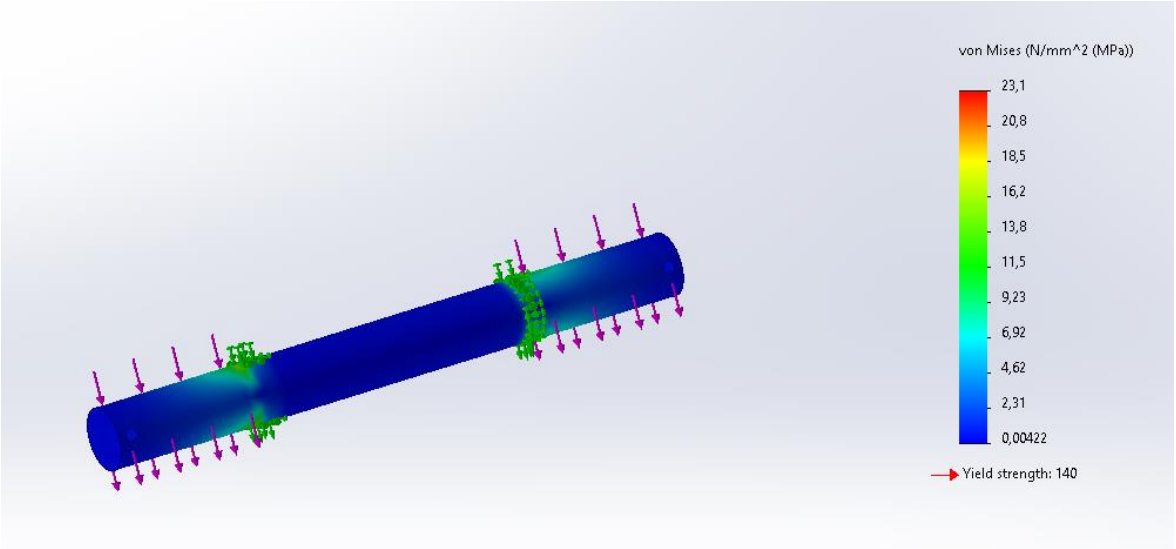

Figure 36 Simulation for the third critical part

Von mises stress looks good since force of 23 N/mm^2 is quite low, but on displacement graph shown interesting picture where can be seen that maximum displacement is 0.000979mm. (Figure 37)

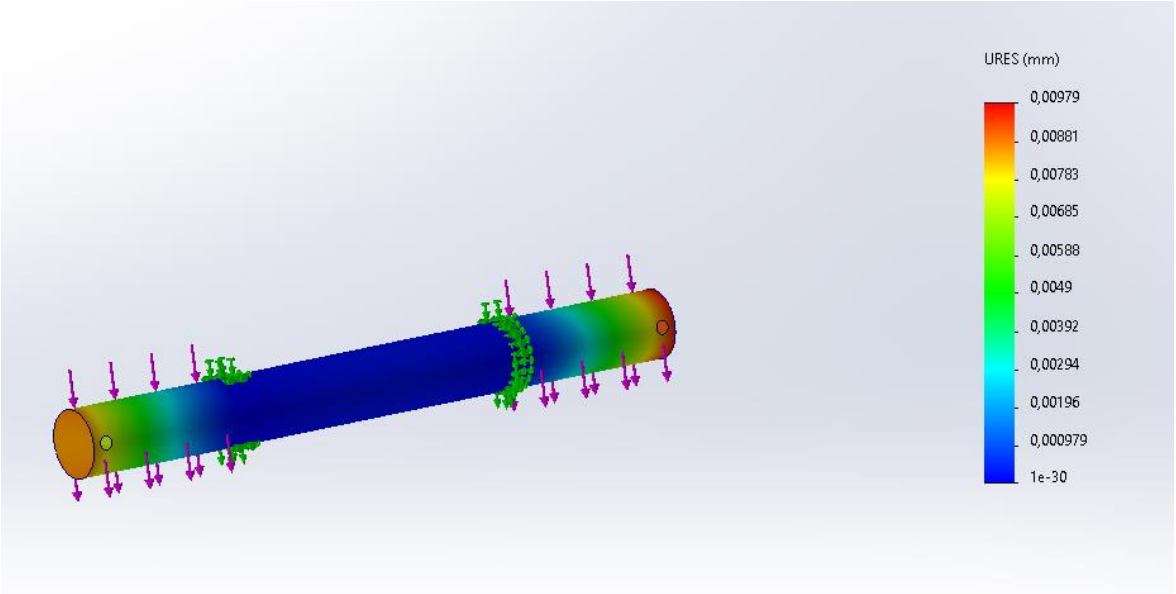

Figure 37 Displacement of the pin in the simulation

It shows that if force applied most critical parts of the component is the ends of the pin, but if look at Figure 22 can be seen that solar panel frame holder apply its force closer to place where it fixed in lower gear that means that mostly simulation correct, and that model will be stable since moment will be much lower than maximum possible.

Manufacturability check of hand-made components

There are few parts which must be checked for manufacturability and below can be found Table 6 which shows manufacturability and its difficulties. Mainly all the parts were modelled with keeping in mind how real manufacturability of those parts.

Table 6 Manufacturability check

#	Part	Manufacturability	Difficulties
1	Lower gear (Figure 25)	+	Difficult in this case that it should be done as 1 part what means that it must

			go throughout different manufacturing stages
2	Upper gear (Figure 24)	+	There should be used CNC machining to create this part. Alternative way is laser cutting
3	Upper motor holder (Figure 23)	+	There can be used CNC machining and bending techniques.

Estimated power output calculations.

For the simulation power needs to be known and it can be calculated throughout taking solar panel size and applying how much elements can be fitted there and after that calculate power according to known number of solar cells and their output:

Size of the panel is 1670mm * 740mm. For example, if specific solar cells taken it has size of 50mm*50mm. In row can be placed 5.96 solar cells what means that can be used 14 solar cells in row and solar panel can have 33 columns, so the final number of solar cells needed for the panel with this size is 33*14=462 solar cells. If each cell has 3.6W real output, final power of the solar panel is 462*3.6W=1662.2W if it has maximum power output. Mainly real results may vary according to the weather conditions, power losses and mainly it will be lower than presented results but still effective.

For the next step usual solar panel output should be taken (Figure 38) and edited considering installed modification (movement mechanism). As a condition will be taken sunny day without clouds in April in the city of Lappeenranta, Finland.

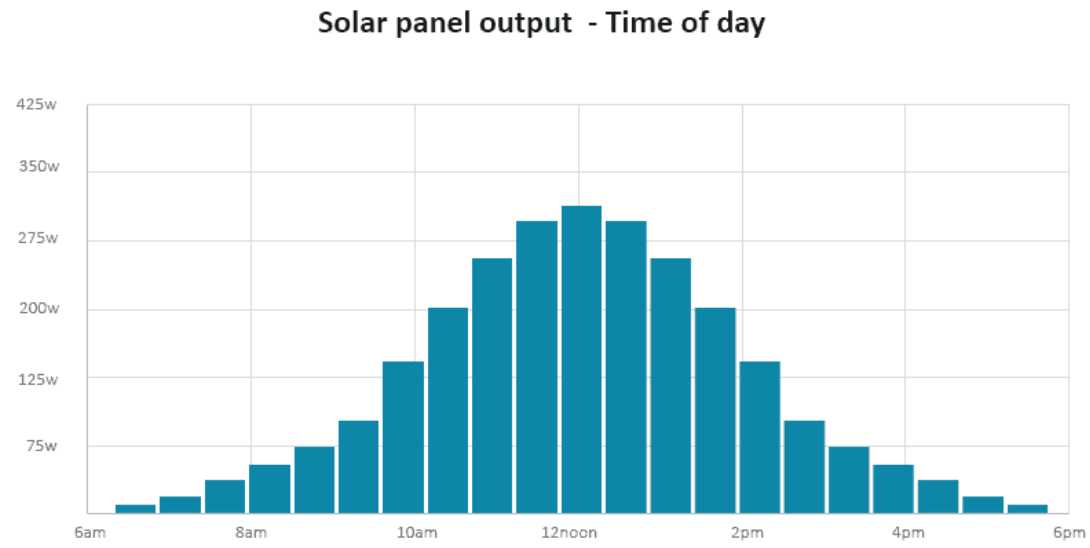

Figure 38 Usual solar panel output graph. (Go Quotes Pty Ltd, 2022)

According to 'TimeAndDate' website (Time And Date AS.) on April 28th at current location sunrise happens at 6:44 and sunset at 19:42. According to this data graph can be edited taking this data into account and how it can look in real life case can be seen on Figure 31. There shown that way from 0% output to 100% shortens, what means productive time gets higher and mostly time when solar panel produce 0 while daytime gets eliminated.

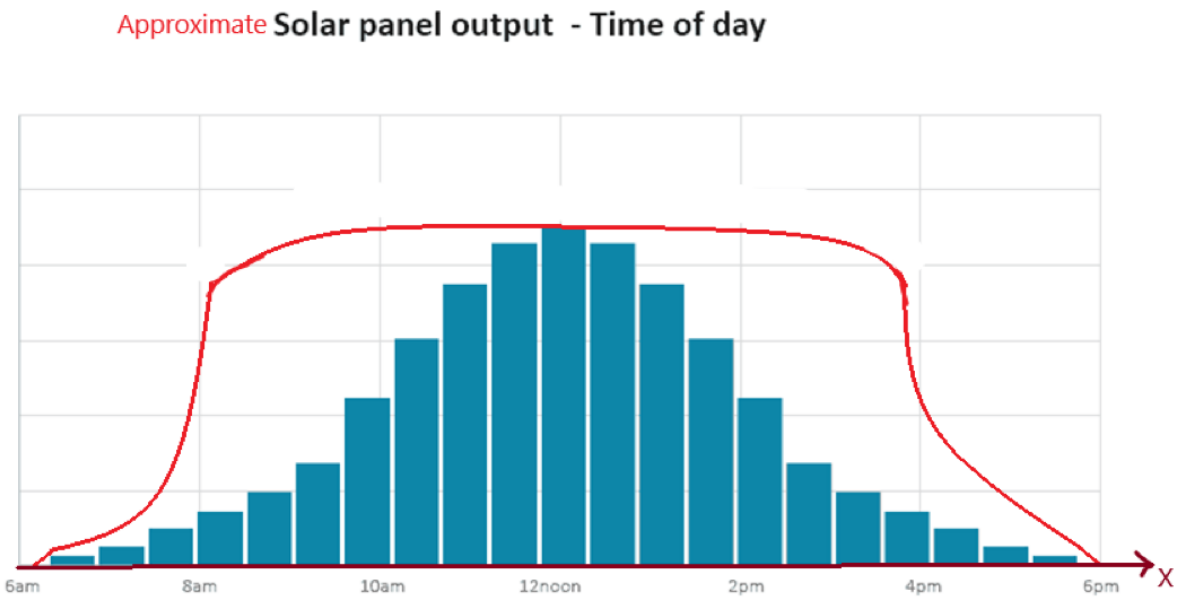

Figure 39 Approximate solar panel power output

5 Summary and conclusion

As a summary, it can be stated that a mechanism has been developed and explained which effectively helps to move a solar panel so that it is always facing the sun. As previously demonstrated, this helps to extract as much energy as possible from the panel, while the low consumption of the two motors can be neglected in the results. This means that all technical goals have been achieved, and approximate results have been presented to illustrate the effectiveness of the system.

The main objective of this work was to demonstrate the usefulness and benefits of such systems, as well as their limitations. The system that has been developed was designed with various weather conditions in mind, as well as ease of installation and manufacturing. It consists of only three parts, which may be challenging to manufacture, but they provide an easy way for the panel to move.

One potential modification to this system that has been considered is to reduce the size of the lower gear, which would require less material and result in higher durability. Another possibility is to rework the mechanism for rotation along the X-Z axis in a more efficient way, but this would require the use of multiple motors instead of just one. These are just a few examples of the potential modifications that could be made to improve the system even further. However, the goal was to create a system that is not only efficient and effective, but also easy to install and maintain and presented system fulfill all the needed requirements.

For those who would like to get model and test or use it for their own purposes 3D model can be found on GrabCad (Last link in reference list).

References

Online Solar, LLC. Photovoltaic effect, available at https://www.mrsolar.com/photovoltaic-effect/ retrieved on December 1, 2022

Online Solar, LLC. What is solar panel, available at https://www.mrsolar.com/what-is-a-solar-panel/ retrieved on December 1, 2022

Electrical4U. Figure 2, available at https://www.electrical4u.com/what-is-photovoltaic-effect retrieved on December 2, 2022

U.S Department of energy. Solar cells, available at https://www.energy.gov/eere/solar/solar-photovoltaic-cell-basics#:~:text=Solar%20cells%20made%20out%20of,original%20power%20after%20this%20time Retrieved on December 2, 2022

U.S Department of energy. Figure 3, available at https://www.energy.gov/eere/solar/solar-photovoltaic-cell-basics Retrieved on December 2, 2022

Clean energy reviews. Figure 4, available at https://www.cleanenergyreviews.info/blog/solar-pv-cell-construction. Retrieved on December 2, 2022

YouTube (a). Kreosan. 2019. How to EARN on Solar Energy by trading electricity from a homemade power plant. May 18,2019. Available at https://www.youtube.com/watch?v=iUd5CzkahWg retrieved December 3, 2022.

Wellste Aluminum, Figure 6, available at https://www.wellste.com/aluminum-solar-panel-frame/ retrieved on December 3, 2022

Alex Muir, 2022, Hydraulic system. Available at https://www.howacarworks.com/basics/how-the-braking-system-works. Retrieved on December 4,2022

Learn Driving Tips, Hydraulic system. Available at https://learndriving.tips/learning-to-drive/car-brakes-tutorial/how-car-brakes-work/. Retrieved on December 4,2022

Learn Driving Tips, Figure 7. Available at https://learndriving.tips/learning-to-drive/car-brakes-tutorial/how-car-brakes-work/. Retrieved on December 4,2022

Learn Mechanical Engineering, Figure 8. Available at https://learnmech.com/components-fuctions-hydraulic-syste/. Retrieved on December 4,2022

Whyps, April 2, 2019, Table 1. Available at https://whyps.com/hydraulic-system-advantages-and-disadvantages Retrieved on December 4,2022

Norgren Ltd 2022, Pneumatic system. Available at https://new.norgren.com/en/support/blog/what-is-pneumatics . Retrieved on December 5,2022

Global Electronic Services, 2022, Figure 9. Available at https://gesrepair.com/pneumatic-system/ . Retrieved on December 5,2022

Interclass, 2012, Table 2. Available at http://ie35int.blogspot.com/2013/05/the-advantages-and-disadvantages-of.html . Retrieved on December 5,2022

Ispatguru, 2019, Figure 10. Available at https://www.ispatguru.com/basics-of-pneumatics-and-pneumatic-systems/. Retrieved on December 5,2022

EnergySage, Inc 2022. Pros and cons. Available at https://news.energysage.com/what-is-the-power-output-of-a-solar-panel/. Retrieved on December 6,2022

Hydrastar Ltd. 2022. Pneumatic system components. Available at https://blog.hydra-star.co.uk/basic-components-pneumatic-system/. Retrieved on December 6, 2022.

Solar MEMS Technologies S.L, 2022. Solar tracker. Available at https://www.solar-mems.com/solar-tracking/. Retrieved on December 6, 2022

YouTube (b). Kreosan. 2019. How to EARN on Solar Energy by trading electricity from a homemade power plant. May 18,2019. Available at https://www.youtube.com/watch?v=iUd5CzkahWg retrieved December 6, 2022.

NSW Government, 2022. Solar cell material. Available at https://www.planning.nsw.gov.au/News/2019/Top-four-metals-and-minerals-that-help-solar-panels-work. Retrieved on December 7, 2022

The Aluminum Association, 2021. Recyclability of aluminium. Available at https://www.aluminum.org/Recycling. Retrieved on December 7, 2022

SHC Group Company, 2022. What is calcium carbonate. Available at https://limestone.com.vn/what-is-calcium-carbonate. Retrieved on December 7, 2022

Asahi India Glass Limited, 2022. Tempered glass. Available at https://www.aisglass.com/tempered-glass-why-do-i-need-my-home-windows-tempered-2/. Retrieved on December 7, 2022

GrabCad, 2022. Eslam Helmy November 2, 2022. Solar panel model. Available at https://grabcad.com/library/solar-panel-92. Retrieved on December 8, 2022.

Off Grid World, 2022. Available at https://offgridworld.com/how-to-get-off-grid-from-here-step-2/. Retrieved on December 10, 2022.

BDG Media, Inc, 2022. Available at https://www.inverse.com/article/53848-professor-increases-solar-panel-efficiency-32-percent-using-a-water-bucket. Retrieved on December 14, 2022.

Distrelec Schweiz AG, 2022. Available at https://www.elfadistrelec.fi/fi/vaihteistolla-varustettu-dc-moottori-39-mm-15-24-vdc-micro-motors-rh158-15-24v/p/15448352?cq_src=google_ads&cq_cmp=18875221639&cq_con=148551644572&cq_term=&cq_med=pla&cq_plac=&cq_net=g&cq_pos=&cq_plt=gp&&cq_src=google_ads&cq_cmp=18875221639&cq_con=148551644572&cq_term=&cq_med=pla&cq_plac=&cq_net=g&cq_pos=&cq_plt=gp&gclsrc=aw.ds&gclid=EAIaIQobChMI1eqR46z7-wIVF3AYCh2PQQpREAQYASABEgKJn_D_BwE&gclsrc=aw.ds . Retrieved on December 15, 2022.

Go Quotes Pty Ltd, 2022. Available at https://gosolarquotes.com.au/what-time-of-day-are-solar-panels-most-efficient/. Retrieved on December 25, 2022

D&E Bearings, 2022. Available at https://debearings.com/product/wb802-wf-wb802/. Retrieved on December 25, 2022

Omni Calculator sp. z o.o. 2022. Available at https://www.omnicalculator.com/physics/wind-load. Retrieved on December 26, 2022.

Time And Date AS, 2022. Available at https://www.timeanddate.com/sun/finland/lappeenranta. Retrieved on December 26, 2022

3D model of developed mechanism. Available at https://grabcad.com/library/solar-panel-with-movement-mechanism-1.