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# SELECTION OF DRIVE SYSTEM FOR HELIOSTAT OF CONCENTRATED SOLAR THERMAL POWER PLANT

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**ABSTRACT:** With the advancement in the domain of science and technology, we witness a lot of development in energy harnessed from sun. Concentrated solar thermal technologies are frequently used as a source for modern day power generation. Past decade has shown huge development in solar power tower technologies. As we know, heliostat is building block of solar thermal tower power plant and efficiency of the plant depends upon how accurately it reflects the light on receiver placed on the top of the tower. In this research, an effort is made to select the drive system for tracking system of the heliostat. In the start, a review of different tracking system is presented. Advantages and disadvantages of all these systems are enlisted. Based on this review, it is concluded that slew drives is best drive system for tracking the heliostat of the solar thermal power plant.

**Keywords:** Tracking system, heliostat, solar tower power plant, drives.

## INTRODUCTION

A rise in the global economy and modern life style is much dependent upon the conventional energy resources (Yilmaz *et al.*, 2019; Kang *et al.*, 2018). These resources are depleting at rapid pace as well as we can see global warming on the rise (Guo e*t al.*, 2019; Okonkwo *et al.*, 2018). This has forced the world to shift away from fossil fuel technology towards renewable energy technologies (Mahboob *et al.*, 2018; Raza *et al.*, 2018; Fares *et al.*, 2018) like wind, solar etc. Solar technologies vary from small household installation to very large solar power plant. Solar concentrating technologies are mainly used for larger power plants (Carra *et al.*, 2018; Chen et al., 2018) and we can see that number of solar tower power plants is increasing amongst newly installed solar thermal power plants (Chen et al., 2018; Atif and Al-Sulaiman, 2018; Polimeni *et al.*, 2018).

In solar tower power plant, we have a central tower on which receiver is placed (Farges *et al.*, 2018). A large number of mirrors are placed all around the tower known as heliostat field that reflects the light on the receiver placed on the top of the tower (Wagner and Wendelin, 2018; Li *et al.*, 2019). In order to track the sun all day long, a tracking system is placed under heliostat that places it in such a way that rays of sun after striking the heliostat concentrate to the receiver all day long (Hu and Huang, 2018). In order to track the sun accurately special efforts are required by the tracking system (Kribus *et al.*, 2004; Bern *et al.*, 2019). The efficiency of solar tower power plant directly depends upon the efficiency of the optical field (Spelling *et al.*, 2015).

The concentrated light on the receiver heats the High Temperature Fluid (HTF) (Han *et al.*, 2009; Soomro and Kim, 2018). Many types of HTF are used depending upon plant design and its operation like molten salt, liquid sodium (Fritsch *et al.*, 2019; Binotti *et al.*, 2019) etc. This HTF transfers heat from the receiver to the exchanger to generate steam (Igreja *et al.*, 2018). Direct steam can also be generated depending upon the plant design. A storage can also be designed to keep plant operational during no sun (Bayon *et al.*, 2018; Farsi and Dincer, 2019; Prieto *et al.*, 2018). The generated steam runs the turbine and electricity is generated.

**Figure 1: Solar Thermal power plant.**

**Heliostat:** Heliostats is the main component of concentrated solar tower power plant that reflects the sun rays to the receiver mounted on top of the tower (Price *et al.*, 2002) by placing itself at bisecting angle to target and sun.

**Figure 2: Heliostat in Solar Thermal power plant.**

The heliostat has following main parts as shown in figure 3 (Mahboob *et al.*, 2018).

1. Mirror surface
2. Support structure
3. Pedestal
4. Control system
5. Drive system

## MATERIALS AND METHODS

**Tracking system of Heliostat:** A tracker is a system or structure on which mirrors are mounted, that can track an object or something else which will be defined in its controlling mechanism. It can change its position to track that thing or object, if the object is Sun the tracker is known as sun tracker. A tracker may be automatic or manual depends upon its design. A manual tracker usually contains only controller and a driving mechanism. In addition to manual system, a tracker usually requires sensors for its automation. Here we discuss only driving mechanism of tracker. The driving mechanism of tracker uses electric motors, actuators or their coupling with gears, pulley belt system to move or rotate the facet and actually define the degrees of freedom of the tracker.

There are two type of coupling mechanism used in tracker's drive system: Series Coupling and Parallel Coupling. In series coupling, motors or actuators are connected in series to increase the degree of freedom of structure, while in parallel, they are connected in parallel.

Solar trackers are categorized as active and passive on the bases of drive methods.

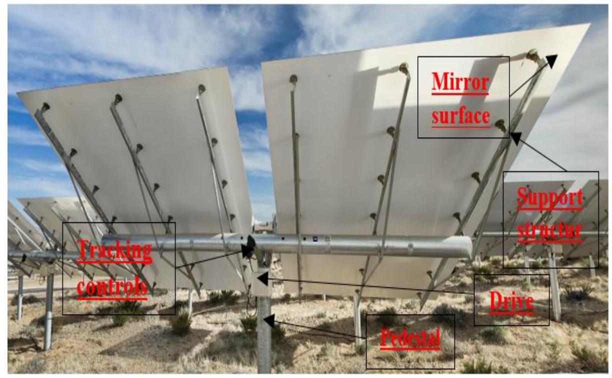


**Figure 3: Parts of Heliostat (Mahboob *et al.*, 2018).**

**Figure 4: High precision solar tracking drive.**

**Passive Trackers:** In these trackers, a volatile fluid is compressed in containers, which is attached to both ends of the rack. The solar radiation creates pressure inside the container which makes the system imbalance and tends the system to move accordingly.

This non-precise orientation makes it unsuitable for concentrating PV collector or tower solar concentrating system. However, it works better in mono or poly crystalline PV panel system. The system does not use any gear and motor for rotation hence, the power is not required.

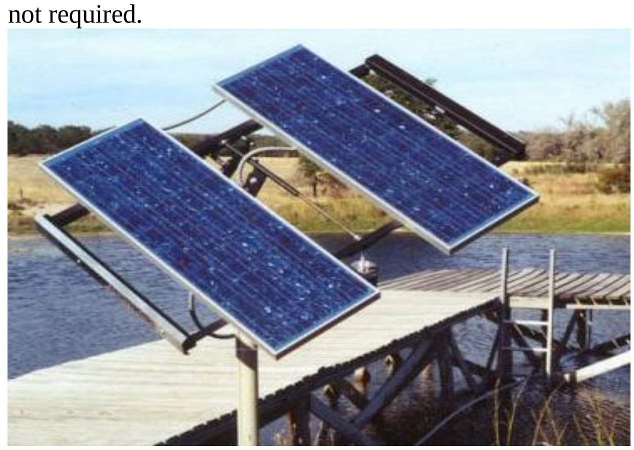

**Figure 5: Zomeworks, Passive Tracker, UTRF-064.**

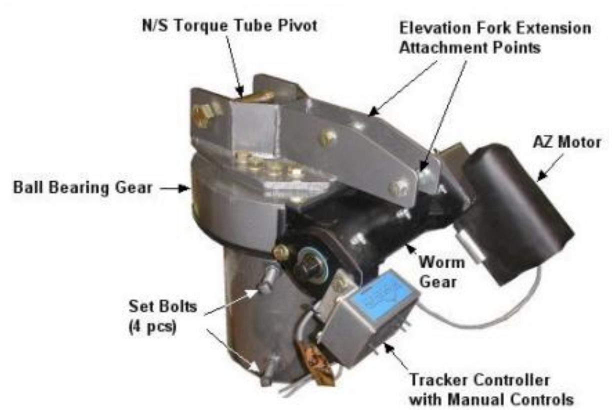


**Figure 6: Dual-Axis, Active Solar Trackers Passive Tracker.**

**Active Trackers:** In these trackers gears and motors are used to drive the panel rack. The control circuit (microcontroller, Programmable Logic Controller (PLC), Personal Computer (PC), etc.) sends command to the motor to rotate – in order to track the sun. Since the motors consume energy, they could be used only once required. Different types of actuators and motors are used in Active Tracking Strategy i.e. Stepper Motors, Servo Motors, Linear Actuators, Linear Servos, Brushless DC Motors etc.

## RESULTS AND DISCUSSION

Drive unit is responsible for movements in the tracking system. Some commonly used drive systems are as follows:

A. Brushed DC Motor
B. Brushless DC Motor
C. Hybrid Stepper Motor
D. Servo
E. Electric Actuator

**Figure 7: DC Motor.**

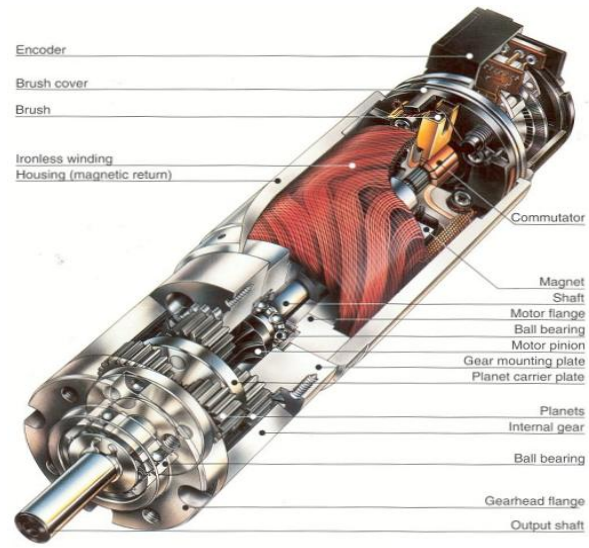


**Figure 8: Brushed DC motor.**

**Brushed DC Motor:** The conversion mechanism of electrical energy into mechanical energy is done by DC motor. William A Lynch (Lynch and Salameh, 1990) used two electro optic sensors with small and cost effective electronic control circuit. Tracking resolution of control circuit was within 0.1 degree. Soteris A Kalogirou (Kalogirou, 1996) used three LDRs to track the sun position, DC motor feedback element sensor gives deviation from zero is 0.2 and 0.05° with 100 and 600 $Wm^{-2}$ solar radiation respectively. Salah Abdullah (Abdallah and Nijmeh, 2004) used two PLC drivers, first for joint rotating and second for east-west tracking. On the fixed surface that is tilted at 32 degree toward south, energy collected was measured and compared. The two axis triangular surfaces have collected 41.34% of solid surface. P. Roth (Roth *et al.*, 2004) used a rectangular pyrheliometer to detects the position of the sun and operating the motor. This system calculates the position of the sun and control the movement under cloudy conditions. Kosuke Aiuchi (Aiuchi *et al.*, 2006) used photo sensor refracting telescope with an equatorial mount. With the cloud sensor, the heliostat operated stably within an error of 10mrad in cloudy weather.

**Figure 9: Polar tracking system (Lee *et al.*, 2006)**

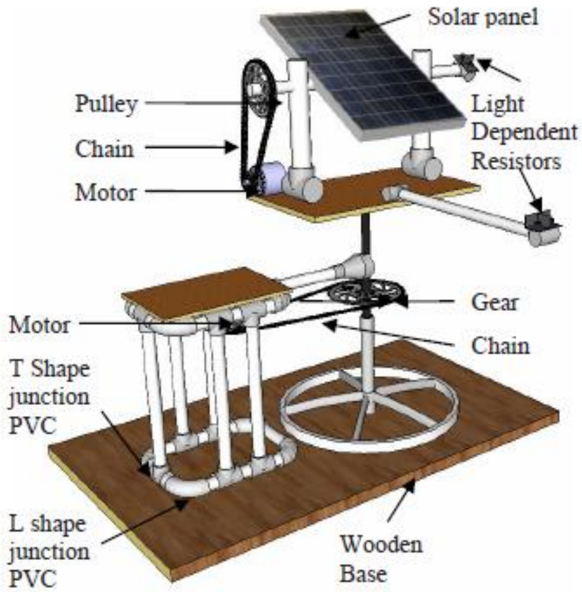

**Figure 10: Two DoF solar tracker (Barsoum, 2009)**

DC motor can be rotated in both directions by inverting the direction of the supplied current. The most effective way to achieve this is the so-called H-bridge (Arturo and Alejandro, 2010). Adrian Catarius used four PV sensors, microcontroller processes, two H-Bridges for the two DC motors two worm gear assemblies and four LED. Nader Barsoum (Barsoum, 2009) used a gear motor, PIC16F84A microcontroller and photocells. Single-axis freedom increase 20% energy output and double-axis freedom increase more than 40%.

Advantages:

- Initial cost is low
- Reliability is high
- Simple logic to control motor speed

Disadvantages:

- Maintenance is high i.e. regularly replacing or cleaning of brushes, commutator and springs
- Life span during high intensity use is low


**Figure 11: Brushless DC motor.**

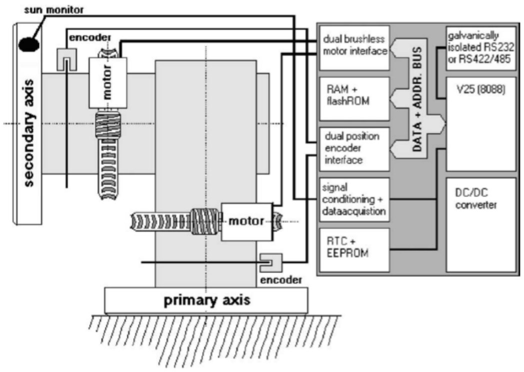

**Figure 12: Block diagram of INTRA sun tracker (Georgiev *et al.*, 2004)**

**Brushless motors:** The brushless motor is a DC motor that works without a mechanical brush and a traditional brush motor switch. It has different characteristics of the brush motor that is more affordable in the long term, granting the fundamental cost is high. In 2003, A. Georgiev (Georgiev *et al.*, 2004) used three Eppley pyrheliometers settled on the INTRA unit that is connected with automatic registering system and UV components used with RTC and RAM powered by power source. Between the radiations the concurrence difference of about 60W/m2 i.e. about 6% of 1000W/m2. The instrument must be sequential against cavity radiometer for successful measurement with this installation.

Advantages:

- Life span is long
- Low maintenance requirements
- Efficiency is high

Disadvantages:

- Initial cost is high
- Motor speed controller is complicated

**Hybrid Stepper Motor:** Hybrid stepper motor is combination of variable reluctance (VR) and permanent magnet (PM) stepper motors. Just like PM motor, it contains a permanent magnet in the rotor teeth. There are two arrangements of the teeth called glasses ring the rotor. One of these rings is South Pole, and other ring is North Pole. Hybrid stepper motor has stator poles just like VR motor. The stator poles in hybrid motor are some of the times called teeth. Steve Schell (Schell, 2011) used a hybrid stepper motors. These motors are incredible fit for the application since they are economical; require no position input sensor and give high torque and low speed yield, which diminishes the measure of fundamental rigging decrease. For a more straightforward proportion of heliostat execution, beam portrayal framework is introduced that focuses on the pinnacle Image Processing of beam anticipated onto these objectives gives estimations of the beam shape just as the pointing exactness.

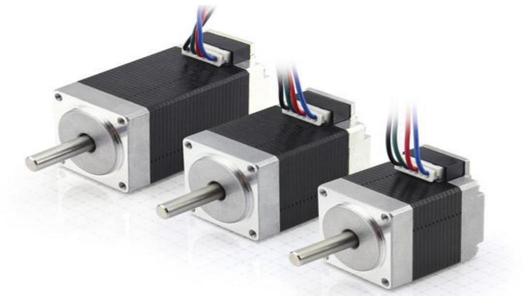

**Figure 13: Hybrid stepper motor.**

Stepper motor is a type of DC brushless motor that equally divides 360 degree in number of steps. The motor uses open loop mechanism but still a controller is required to command the spindle to move or hold at one of these steps. The main disadvantage of these motors is that their torque is decreased with increase in its speed. These motors are used in devices requires high accuracy like 3D Printers etc. Dong Il Lee (Lee *et al.*, 2012) proposed an optimal real time design for solar tracking of heliostat using illuminance sensor (CdS) and Simulink program for maximizing the efficiency of solar absorption in receiver. The maximum error was calculated using simulation which is within 1° between 8:00 am and 5:00 pm. Francisco Duarte (Duarte *et al.*, 2011) developed an open loop dual axis sun tracking mechanism based upon solar astronomical data with which exact position of the sun can be predicted for certain location to move the structure accurately. Stepper motors are used for each axis. The system cost and power usage is low as compared to traditional trackers due to simple hardware. According to several studies, the production is approximated to be increased by 40% using dual axes solar tracking mechanism.

Advantages

- Precise Positioning
- Quite rugged
- Construction is simple
- Little maintenance required and reliable
- At low speeds gives high torque
- No need for position or velocity

Disadvantages

- At high speeds torque is diminished
- Noise and resonance
- Current consumption is high
- Suitable for speeds under 1,000 rpm

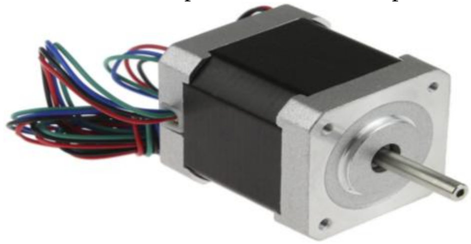

**Figure 14: Stepper motor.**

**Servo Motors:** A servo motor is linear or rotatory actuators used for precise control of velocity, acceleration or position both angular and linear of an object using closed loop mechanism. It uses a potentiometer for its position feedback and need a controller for its operation. They are usually used where high torque is required with increase in speed. They are usually used in automated manufacturing and robotics. P. Roth (Roth *et al.*, 2004) built a hybrid solar tracking electromechanical system using pyrheliometer and four-quadrant photo detector for feedback and centred instrument using servo motor. If the sun is undetected due to clouds in sky, a predefined algorithm calculates the position of sun using astronomical formulas and controls the system, until the sensors can again sense the sun. Ching-Chuan Wei (Wei *et al.*, 2016) proposed a novel method for sun tracking by tracking the brightest region of sky using camera. It is logical to assume that the brightest region of sky represents position of sun. The method is cost effective, real time and accurate in sunny days and building shelters. However, in thick cloudy weather, sun position is possibly far from actual sun centred.

Advantages

- Relative to motor size higher output power
- Vibration and resonance free operation
- Higher efficiency
- High speed and torque operation

Disadvantages

- Stabilize feedback loop tuning required
- Complex Structure
- Encoder is required
- Motor cooling is poor
- Sustained overload can damage the motor

**Figure 15: Servo motor.**

**Actuator:** A linear or prismatic actuator is an electromechanical device used to change the circular motion of an electric motor into linear motion. Linear Actuators have disadvantages sometime because of their non-constant holding force. They are capable of driving larger structures using their slow drive. James Larmuth shows if we use Helio-40, there will be as small effect on cost on selection of tracking algorithm, but have a large effects on packing ratio, optical performance and control of the heliostat. R.B Ashith Shyam (Shyam *et al.*, 2018) proposed a 3-UPU, three degree of freedom parallel manipulator to use electronically reconfigure-able 3-UPU and redundancy to achieve Azimuth-Elevation and Target-Aligned configurations and thus achieve the advantage of both. The serial mechanism has less tracking accuracy as compared to parallel manipulators. A prototype is used and numeric results are validated.

Advantages

- Components can work in complex configuration
- Flexibility of motion control
- High efficiency
- High torque operation is possible
- Low operation and maintenance cost

Disadvantages

- Can be used for moderated speeds only
- High purchase cost

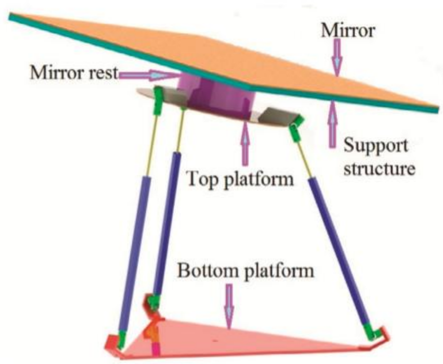


**Figure 16: 3 UPU heliostat and its joints (Shyam *et al.*, 2018)**

**Conclusions:** Different drives of tracking system for heliostat of solar tower power plant are discussed in detail in this article. Advantages and disadvantages of different type of drives for tracking systems are enlisted. Based on this review, followings are conclusion,

Hybrid stepper motor is quite precise and precise tracking of the heliostats is required so that maximum efficiency of the heliostat field can be achieved. Hybrid stepper motor has to operate in harsh desert conditions and it is best suited for these types of conditions due to its rugged nature. Higher Torque requirements are bottleneck in this regard.

Due to large size of heliostat, there is requirement of system with higher torque and drive system that supports higher torque under low speeds. Attaching a gear system will increase moving as well holding torques.

It is recommended that a slew drive can be used for this purpose. DC motor is attached and higher gear ratios enable us to have higher torques at low speeds. Due to low cost brushed motors are usually used. A slew drive system will be used for prototype development, tracking algorithm testing as well as working of the tracking system.

**Future work:** A literature survey for different sensors and controls will be carried out that can be selected alongside these drives. Following activities will be conducted: Proper selection of the control system for these drives is required.

A control system along with sensors can be constructed to increase the reliability and accuracy.

A prototype is to be developed to check all the parameters of the tracking system using hybrid stepper motor

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