Pneumatic Tracking System for Photovoltaic Panel

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Abstract: *Applications that use photovoltaic systems are continuously growing, in recent years, according to EU policies that foster the renewable energy sources. The current trend is to optimizing these systems by ensuring functionality with maximum efficiency. One of the methods of optimization refers to the capture of large quantities of solar energy using tracking systems for photovoltaic panels. The most of photovoltaic tracking systems uses the electric drive. This paper presents another type of tracking system based on a pneumatic drive. Of the existing tracking systems in literature, the pseudo-equatorial system was adopted. This tracking system was particularized for Craiova location.*

Keywords*: tracking system, photovoltaic (PV) panel, pneumatic drive, sun position*

1. Introduction

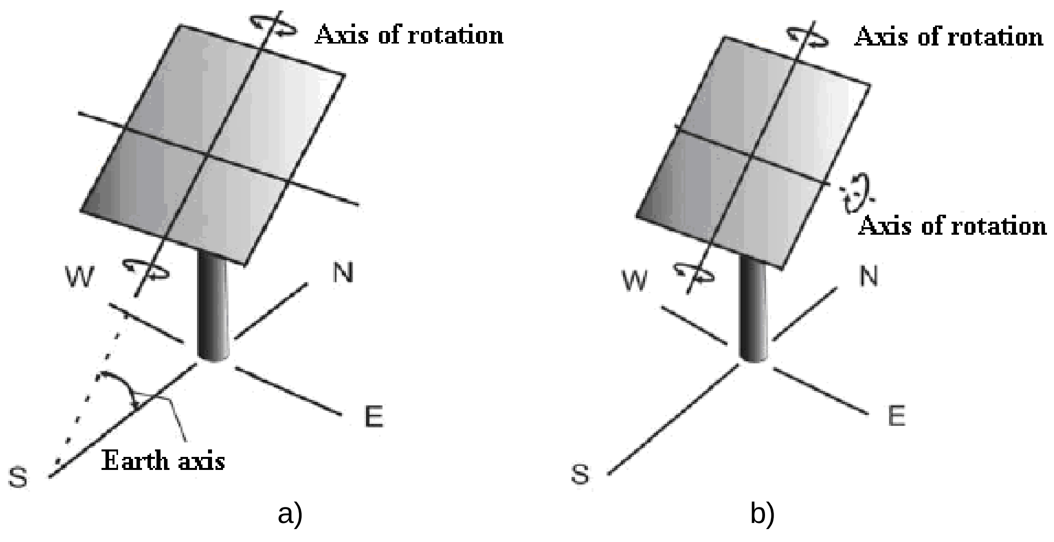
Photovoltaic conversion of solar energy is one of the most attractive and dynamic options to use renewable energy to produce electricity. In order to compete with conventional sources of electricity generation have found solutions to increase the efficiency and decrease the cost price of photovoltaic modules.

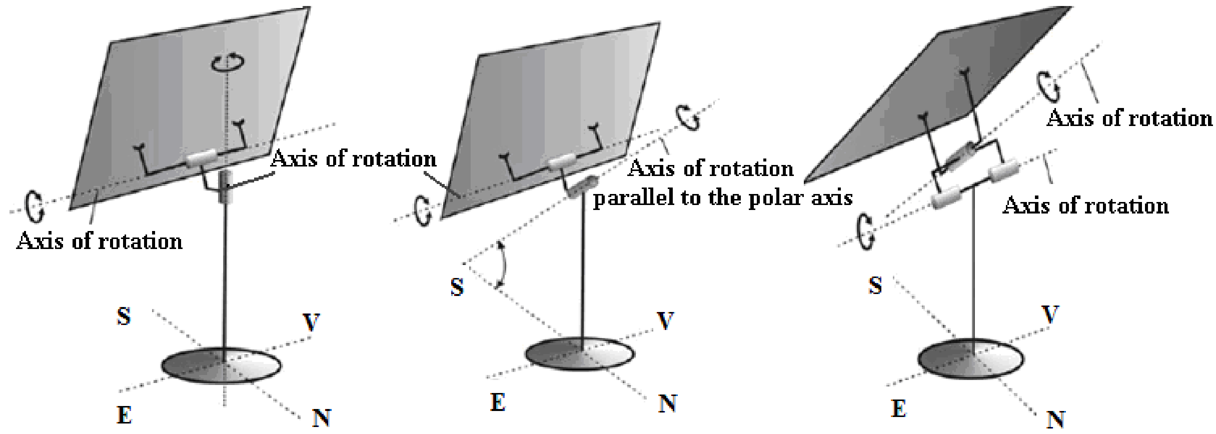
Ideally, a PV panel should follow the sun so that the sun rays fall perpendicular to its surface, thus maximizing solar energy capture and thus we obtain the maximum output power. The tracking systems using controlled mechanisms that allow maximization of direct normal radiation received on PV panel [7].

2. Photovoltaic tracking systems

Electricity production of a PV system depends largely on solar radiation absorbed by the photovoltaic panels. As the sun changes with the seasons and over a day, the amount of radiation available for the conversion process depends on the panel tracking [3, 5, 6, 7].

In practice are two kinds of tracking systems: single axis and double axes tracking systems (Fig. 1). In the case where the two orientation axes 3 types of systems can be distinguished, depending on how the axes are placed and how the two movements are entered into the system [7]: the azimuthally systems, the equatorial systems and the pseudo-equatorial systems. In this paper was considered the pseudo-equatorial system.





b1) b2) b3)

Fig. 1. Tracking systems of PV panels: a) - single axis, b) - double axes, b1) - azimuthal, b2) - equatorial, b3) - pseudo-equatorial

The tracking systems presented above is based on two methods of orientation:
- method based on going through a predetermined trajectory;
- method based on the search of maximum illumination.

In this paper we present a method based on going through prescribed tracks.

3. Determination of PV panel position

It is known that the Earth behaves a complete rotation in a year, around the Sun in an elliptical orbit and a complete rotation around its own axis during 24 hours. Earth's rotation axis has a fixed direction in space and inclined angle $\delta_0 = 23.5^o$ to the perpendicular plane of the orbit (Fig. 2). The angle between the direction to the Sun and the equatorial plane, δ is named declination and varies during the year from 23.5^o, at the moment of the summer solstice (June 21) to -23.5^o, at the winter solstice (December 21st).

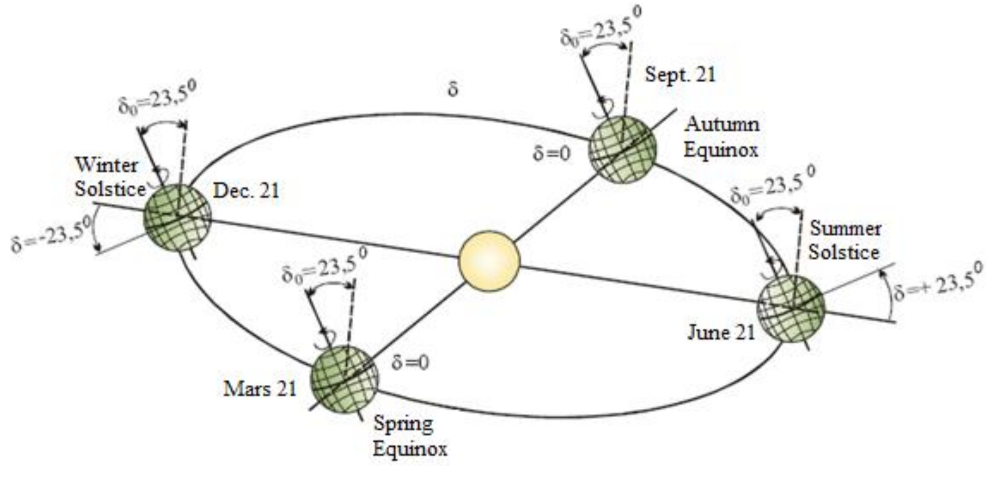


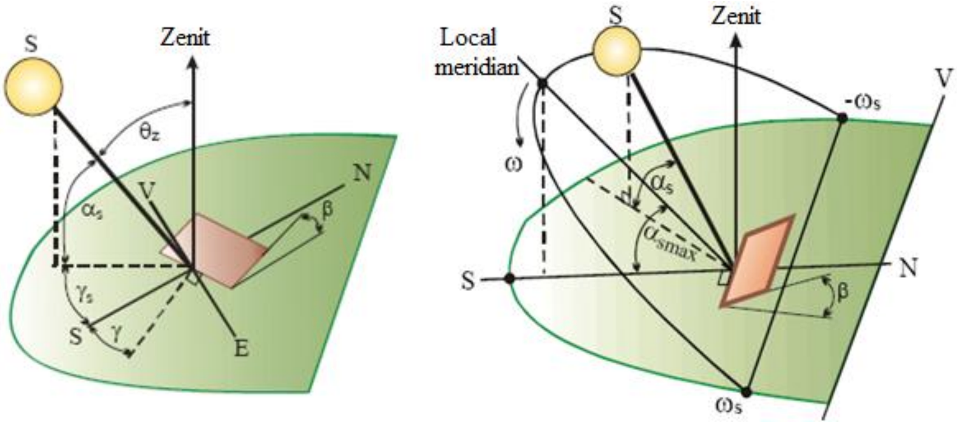
Fig. 2. Earth's orbit and the angle of declination, δ

On 21 March, respectively - September 21 declination δ = 0 and the length of day and night are equal.
Declination can be calculated with the Copper formula [6]:

$$\delta = 23{,}45 \cdot \sin\left(360^o \frac{284+n}{365}\right) \qquad (1)$$

where n - is the number of days in a year, the first day considering January 1. Using monthly average of 'n' values can be calculating the declination of Earth during a year.

Geometric relations between an arbitrarily oriented plane to the horizontal and direct sunlight that falls on the plan at any point of time, the position of the sun to this plan can be described in terms of several angles.
Latitude, φ - angle measured from the equator to the point of interest on the earth's surface, is considered positive for the northern hemisphere and negative - to the south.
The inclination angle of plane β - the angle between the plane and the horizontal surface; 0 ≤ β ≤ 180, (Fig. 3). For normal solar installations, maximum angle does not exceed 90°.
Azimuthally angle, *γ* - the angle between the projection on the horizontal plane perpendicular to the surface of the plan and the local meridian (Fig. 3); equal to zero for that plan south facing; negative - to east, positive - to west; -180 ≤ γ ≤ 180.
Solar azimuthally angle, γs, - the angle between the south and the projection on the horizontal direct radiation (sunlight) (Fig. 3 b); angles measured from south east direction are negative, the measured westward - positive.



a) b)

Fig. 3. Explanation regarding to sun's angles

The angle of elevation of the sun, α_s, - the angle between the horizon and the sun line linking point of interest, or the incident solar beam at the point of interest (Fig. 3).
Zenith angle, θ_z, - the angle between the vertical and the line connecting the sun and the point of interest, or α_s complementary angle (Fig. 3).
Hour angle, ω, - determines the position of the sun in the sky at a given moment. Equals zero when crossing the local meridian sun, ie when midday positive and negative east - west (Fig. 3 b). Accordingly, ω_s corresponds to the angle of sunrise, and (- ω_s), the angle of the sun dusk.
It is obvious that in an hour the sun across the sky at an angle equal to 15^o, and his position at any time T is determined by the expression:

$$\omega = 15 \cdot (12 - T) \tag{2}$$

If you know the angles δ, φ and ω, then easily determine the position of the sun in the sky for the point of interest for any time, any day, using the expressions [6]:

$$\sin\alpha_s = \sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega = \cos\theta_z \tag{3}$$

$$\cos\gamma_s = \frac{\sin\alpha_s \sin\varphi - \sin\delta}{\cos\alpha_s \cos\varphi} \tag{4}$$

In equation (3) by imposing the condition, calculate east respectively west angle hourly of the sun from the relationship:

$$\omega_s = \pm\cos^{-1}(-\tan\varphi \cdot \tan\delta) \tag{5}$$

For every day of the year in (4) with declination δ previously determined from (1) for a time T is determined the hour angle ω and knowing the latitude φ is determined the sun elevation angle αs.

In figure 4 is presented photovoltaic panel, P directed to the South. Surface of panel P is inclined to the horizontal with β angle.

Solar radiation on the PV panel will be highest when the afternoon when the sun elevation angle, αs is the maximum distance and sunlight will be minimal time and angle ω = 0. This situation will occur where direct radiation is perpendicular to the surface of the PV panel, P.

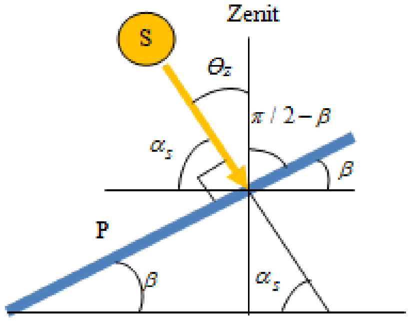


Fig. 4. Direct solar radiation on an inclined plane in midday: ω=0; γ=o;

Figure 4 shows that θz = β, and angle of the panel on S-N direction (elevation), from the horizontal plane is determined by the relationship:

$$\cos\theta_z = \sin\delta \sin\varphi + \cos\delta \cos\varphi = \cos(\varphi - \delta) \tag{6}$$

$$\beta = 2\pi - (\pi + \alpha_s) \tag{7}$$

Based on present relationships above, customizing for city of Craiova was obtained graphical representation of specific angles describing the position of the sun in the sky and the PV panel position (Fig. 5, Fig. 6, Fig. 7).

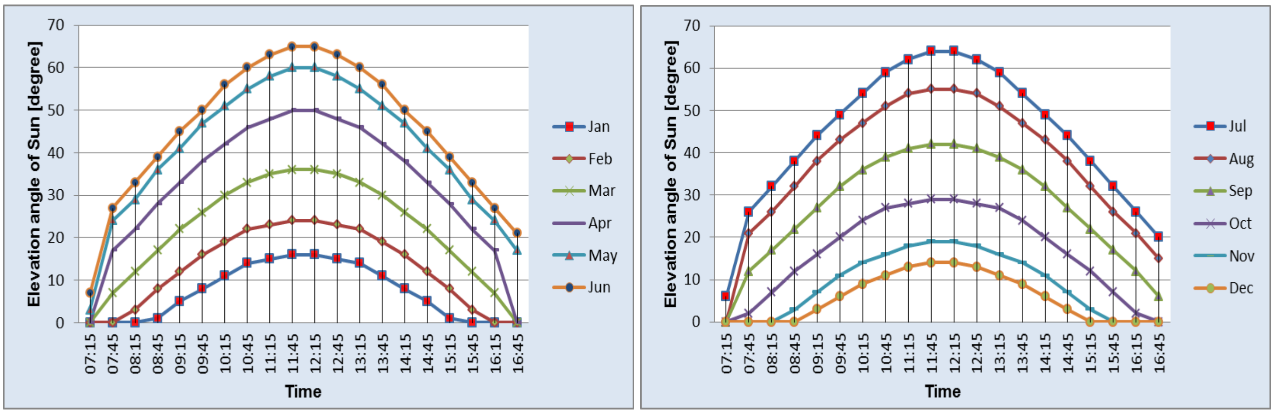


Fig. 5. Elevation angle of sun for each month of year

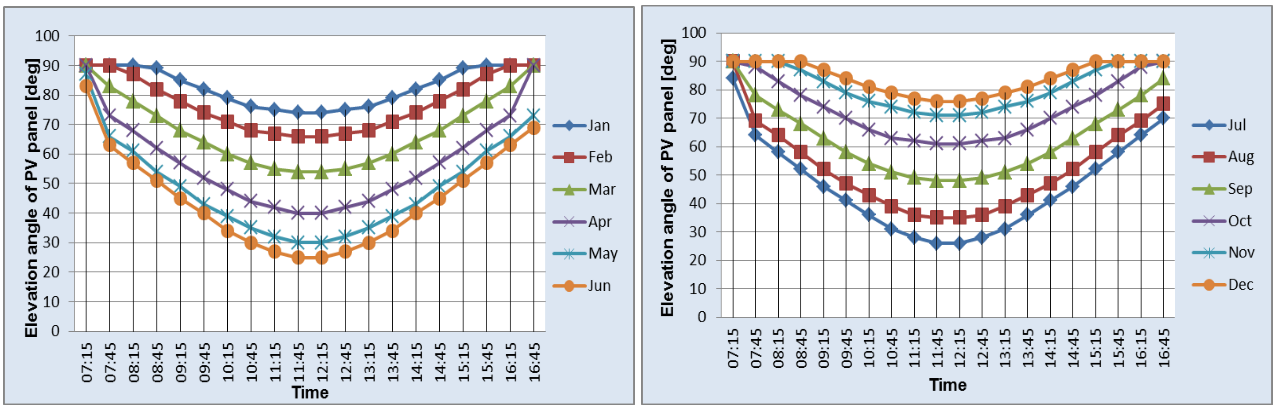


Fig. 6. Elevation angle of PV panel for each month of year

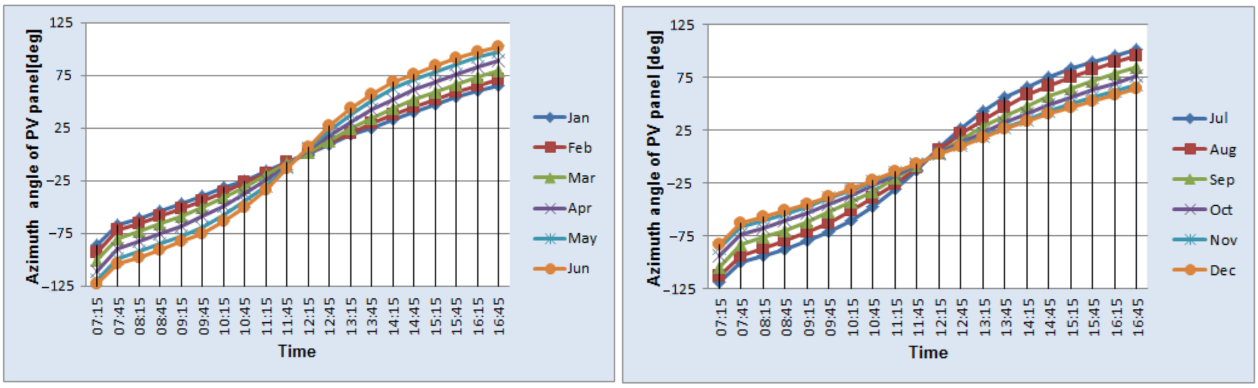


Fig. 7. Azimuth angle of PV panel for each month of year

The graphs above reveals PV panel position every 30 minutes throughout the day. Knowing the position of the panel can develop the control algorithm of pneumatic tracking system.

4. Simulation of pneumatic tracking system

The most of PV tracking systems uses the electric motors. In this paper is proposes another type of tracking system that uses a pneumatic drive (Fig. 8). Were considered the following advantages:
- the forces, moments and engine speeds can be adjusted easily using simple devices;
- pneumatic motor overload does not introduce risk of damage;
- pneumatic transmissions allow starts, stops, frequent and sudden changes of direction without risk of damage;
- compressed air is relatively easy to produce and transport networks is environmentally friendly non-flammable;
- can be stored in high quantity;
- risk of injury is reduced;
- easy maintenance.

For achieving the structure and pneumatic control of system and also, to simulate the operation has been used dedicated software named FluidSim [16], (Fig. 9, Fig.10).

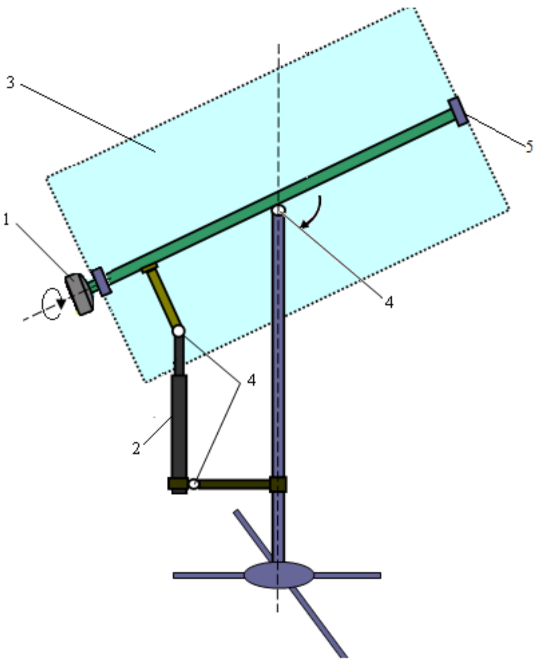


Fig. 8. Structure of pneumatic tracking system
1- Semi-rotary actuator; 2-liniar cylinder; 3- PV panel; 4- joints; 5- fixture for PV panel

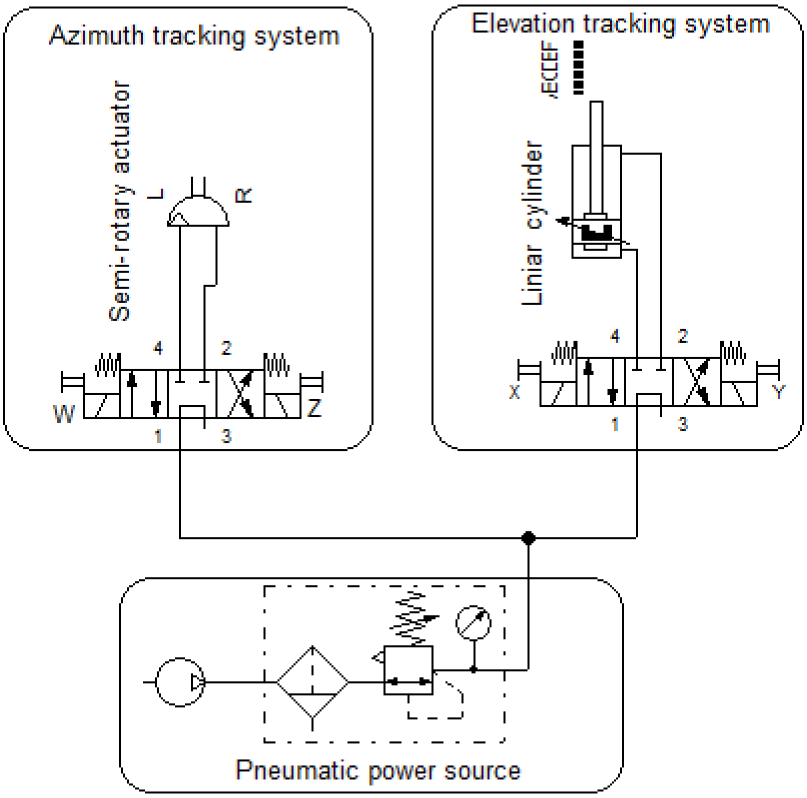


Fig. 9. Structure of pneumatic drive

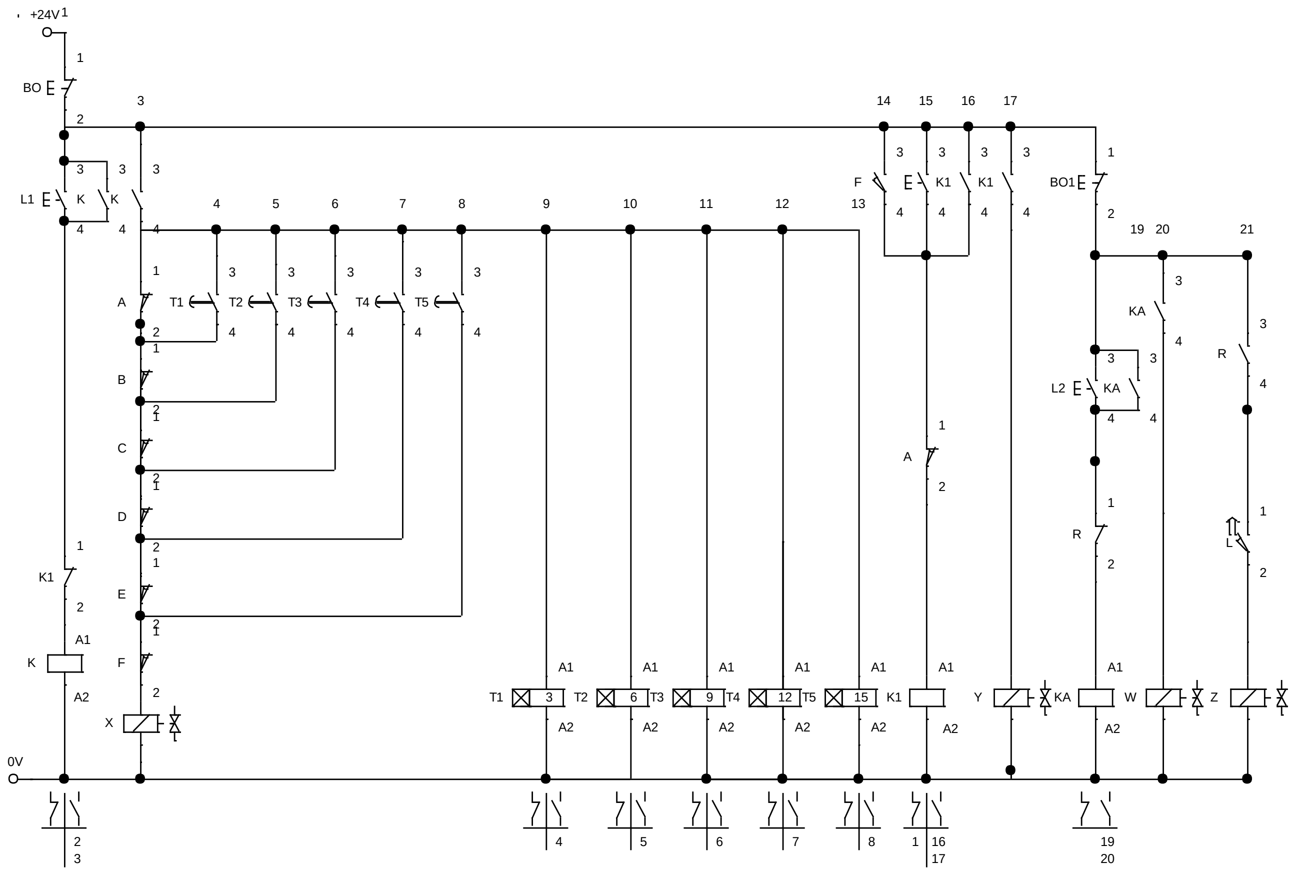
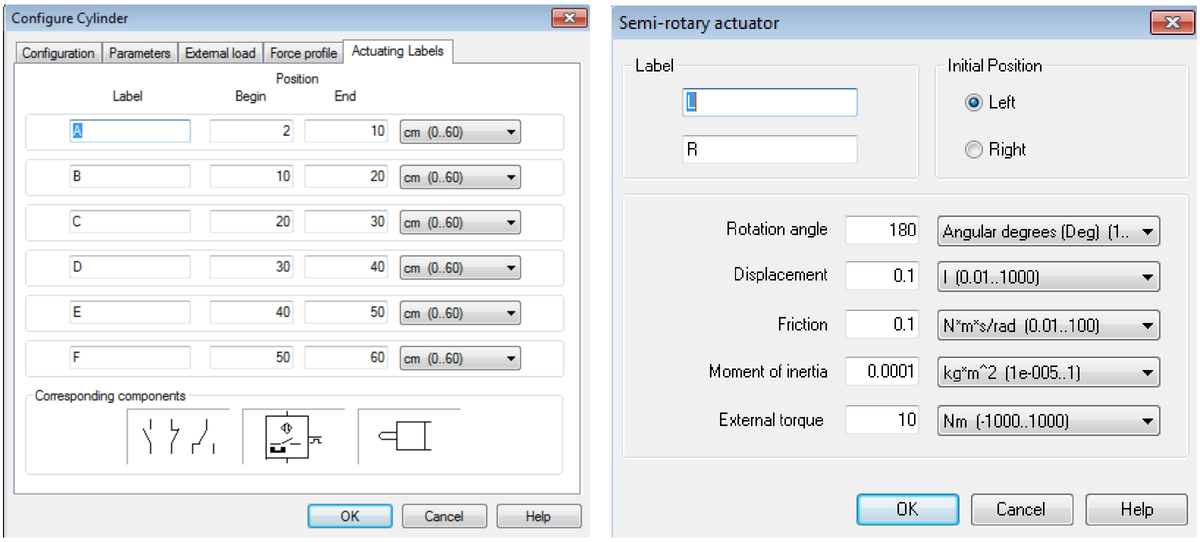


Fig. 10. Electrical circuit for control of pneumatic drive

Positioning of the PV panel on elevation is made by a linear cylinder and on azimuth by a semi-rotary pneumatic motor (Fig. 9). The position of linear cylinder is controlled by limit switch (A, B, C, D, E, F) and timer relays (T1, T2, T3, T4, T5), (see Fig. 10).
Figure 11a) reveals position of limit switches according to the cylinder rod. The first limit switch activating (A) lead to interrupt the power supply to X solenoid valve. After timing generated by a time relay the X solenoid valve is again activated and cylinder is put in motion until reaching another limit switch. (see Fig.10). The sequences are repeated until reaching the ultimate limit switch (F). Now the valve is commanded by a Y solenoid, and the piston of cylinder is returned to initial position.
The movement of semi-rotary pneumatic motor is controlled by pneumatic valve provided with the solenoids W and Z respectively. The semi-rotary pneumatic motor performs a rotating motion between R and L limits at an angle of 180^{o}.
The FluidSim dedicated software allows viewing the characteristic parameters of pneumatic drive. Figure 12 presents the results of simulation for linear cylinder.



a) b)

Fig. 11. Configuration of pneumatic actuators: a) linear cylinder; b) Semi-rotary actuator

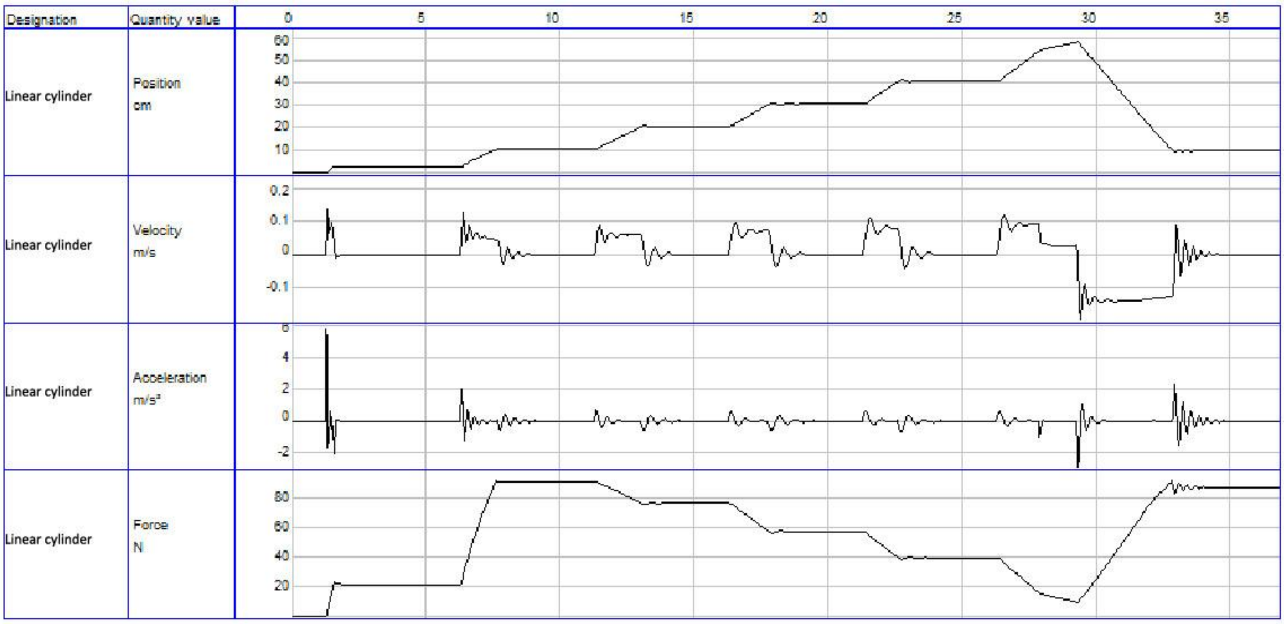


Fig. 12. Results of simulation for linear cylinder

5. Conclusions

In this paper were presented aspects of tracking systems for PV panels. Particularly was presented a pseudo-equatorial tracking system type based on a pneumatic drive. Simulation of automatic drive system was performed with dedicated software named FluidSim. Simulation results showed the evolution of the typical parameters of pneumatic drive. The practical and experimental aspects will be presented in a future work.

Acknowledgments

This work was partially supported by the grant number 29C/2014, awarded in the internal grant competition of the University of Craiova.

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