Automatic Tracking for Parabolic Trough Solar Concentrator

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Abstract: ***A parabolic trough solar collector uses the glass mirror as a reflecting material in the shape of a parabola in order to reflect and concentrate the sun radiation towards a receiver tube located at the focus of the parabola. Various solar tracking systems have been developed by various researches in the past decades. A tracking system is still required which can track the sun on real time basis without any geographical data. In the present work, an automatic sun tracking system for parabolic trough collectors is designed for its feasibility. It is found that the automatic sun tracking system provides higher efficiency when compared to manually operated and fixed collectors. In this work, a direct formula is proposed for design of robust PID controller for sun tracking system using quadratic regular approach with compensating pole (QRAWCP). The main advantage of the proposed approach is that it eliminates the need to use recently developed iterative software computer techniques which are time consuming, computationally inefficient and also with this new approach there is no need to obtain boundaries of search space. In order to illustrate the effectiveness of the proposed approach, performance of the sun tracking system is compared with the recently applied tuning techniques for sun tracking systems such as Particle Swarm Optimization (PSO), Firefly Algorithm (FFA) and Cuckoo Search Algorithm (CSA).***

Keywords: PTC: Parabolic Trough Collector, CSP: Concentrating Solar Power, MNS: Molten Nitrate Salt, SEGS: Solar Electric Generation System, HTF: Heat Transfer Fluid

1. Introduction

In today's technological era, electrical and electronic devices are developing rapidly. Therefore, the energy demand of every country is rising. Moreover, an important attention is also towards the environment. This requirement of energy has to be satisfied without causing harm to the delicate balance of Earth's mother nature, mainly by adopting renewable resources. Renewable energy is available in different forms such as wind power, hydro-power, solar energy, geothermal energy, bio-energy, etc. In order to utilize this energy, power plants have to be installed at suitable geographical locations. From all the previously mentioned energy sources, solar energy plays a pivotal role. Solar energy is the fastest growing renewable energy source due to the fact it has the leas installation costs when compared to other types.

Egypt is an African country with a population of over 100 million people, located between 22^0 and $31^0 36'$ N of the equator and between 24^0 and 37^0 E of Greenwich. It's a country with area of more than 1 million square meters. The country has a typical Middle Eastern weather characterized by hot and dry summers and mild winters. The average temperature during summer and winter seasons are 32^0C and 20^0C respectively. It is a country with a high potential of natural resources, approximately 4189 billion barrels of oil reserves and an estimated 77200 billion cubic meters of natural gas reserves, as the reserves are in the form of both mainland and costal deposits. While more than 90% of the Egyptian generated electricity comes only from oil and natural gas, the major problem which Egypt encounters, especially in the energy sector, is the dynamic growth of its population, which is estimated by around 1.3% per year. Consequently, this growth increases the energy demand, which eventually fastens the rate of depleting the country's major resources [1].

It has been noted earlier that some of the attractive features of a flat plate collector are the simplicity of design and ease of maintenance. The same cannot be said of concentrating collectors which usually have to follow or track the sun so that the beam radiation is directed onto the absorber surface. The method of tracking adopted and precision with which it has to be done varies considerably. In collectors providing a low degree of concentration, it is often sufficient to make one or two adjustments to the collector's orientation every day and it can also be done manually. However, with collectors providing a high degree of concentration, it is necessary to make continuous adjustments to the collector's orientation. The need for some kind of tracking introduces a certain amount of complexity to the design, while maintenance requirements are also increased and all these factors contribute to the overall cost. An added disadvantage is the fact that diffuse radiation is lost due to not being focused.

2. Solar Tracking Systems

Like any collector of a CSP system, parabolic troughs have to track the sun in order to reach a continuous concentration of the direct solar radiation. As line concentrating collectors, parabolic troughs have a one-axis tracking system (while point concentrating systems need two-axis tracking). Figure 2 gives a general idea of the tracking of a parabolic trough. The rotational axis is normally at the vertex line of the parabolic trough or in a parallel position slightly below it.
The collector movement is realized by a drive unit that moves a collector assembly (a row of connected collector modules). Collector assemblies can be very long. The

Eurotrough collector reaches 150m and the new Heliotrough collector even 191m. The drive unit must be sufficiently strong to be able to move such a large collector assemblies and to maintain them in the right position also under wind conditions. Mechanically, the drive unit can be realized as a motor-gearbox unit, or as an electro-hydraulic unit system. In the case of the latter, the drive unit consists of two cylinders, which are controlled by two valves, determining the direction of rotation. Dependent on the location of the collector in the solar field, the cylinders differ in size. The collectors at the border of the solar field need a stronger hydraulic drive, and consequently bigger cylinders, because they have to withstand higher wind loads than the collectors in the center of the solar field.

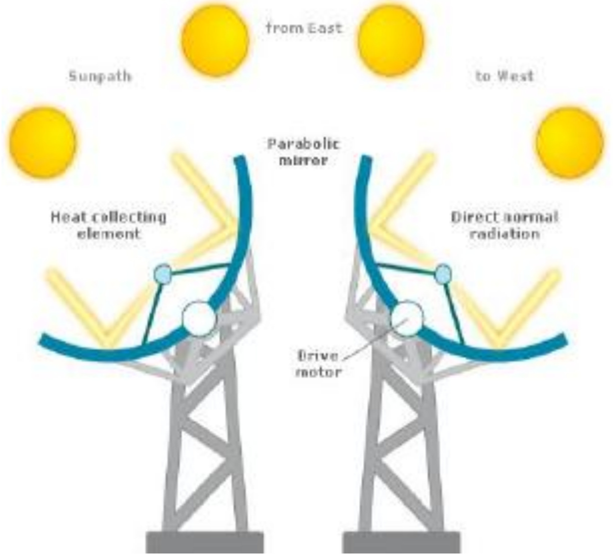

Figure 1: Single axis tracking of parabolic troughs [2]

3. Solar Tracking Modeling

The schematic model is shown in Figure 3. The direct normal irradiance (DNI) could be obtained from solar monitoring stations or theoretical derivation. The incidence angle is the angle between the beam radiations on a surface and the normal to the surface. It could be derived. The incident angle is calculated as:

$$\delta = 23.45 \sin\left(360\frac{284+n}{365}\right)$$

$$\cos\theta_z = \cos\emptyset\cos\delta\cos\omega + \sin\varphi\sin\delta$$

$$\cos\theta = \sin\delta\sin\emptyset\cos\beta - \sin\delta\cos\emptyset\sin\beta\cos\gamma + \cos\delta\cos\emptyset\cos\beta\cos\omega + \cos\delta\sin\varphi\sin\beta\cos\gamma\cos\omega + \cos\gamma\sin\beta\sin\gamma\sin\omega$$

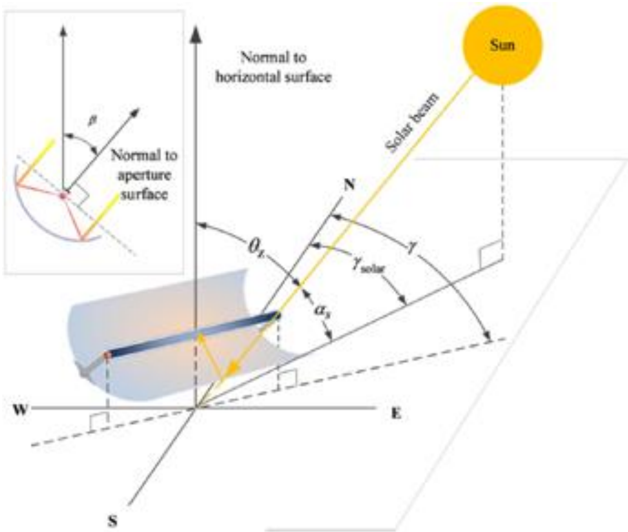

Figure 2: Schematic of model [3]

The scope of this thesis is parabolic trough collectors which are tracking the sun on one axis continuously in order to focus solar radiation to the absorber. There are two alternatives for a PTC solar array in terms of tracking axis. One with tracking about a N-S axis (North-South Axis Tracking) and the other with tracking about an E-W Axis (East-West Axis Tracking). Table 1 illustrates a comparison between the two.

Table 1: Recirculation against once-through and injection concepts

	N-S Axis Tracking	E-W Axis Tracking
Angle of incidence	$\cos\theta = (\cos^2\theta_z + \cos^2\delta\sin^2\omega)^{\frac{1}{2}}$ (4)	$\cos\theta = (1 - \cos^2\delta\sin^2\omega)^{\frac{1}{2}}$ (5)
Perfect conditions	•The angle of incidence for perfect N-S axis tracking is minimized in the morning and evening •N-S axis tracking maximizes resources in the morning and evening	•The angle of incidence for perfect E-W axis tracking is always zero at solar noon •E-W tracking axis tracking minimizes resources at solar noon
For Egypt	N-S axis tracking maximizes summer and annual resources. As a result, most of the PTC solar thermal power plants are N-S oriented.	E-W axis tracking maximizes winter resources

4. Computer Code

The present work will focus on the modeling of a solar tracking system using PID controller suitable for the climatic and geographical condition of Egypt. This can be done by modeling the PID controller to derive the sun position for different months. The objectives of this present work are:

1) To analyze the viability of the parabolic trough collector through a simulation model, taking solar transient conditions into account.
2) Examine the theatrical approach of parabolic trough solar tracking model, taking into consideration the time response analysis and loop robustness. The analysis was conducted by a QBASIC program to provide the opportunity of altering or changing system components and parameters.
3) To determine the superiority of the proposed PID controller model, Quadratic Regulator Approach with Compensating Pole (QRAWCP) approach, in comparison with other PID controller techniques

In this work, a new method is proposed for obtaining direct formula for designing PID controller using Quadratic Regulator Approach with Compensating Pole (QRAWCP). The upside of this method is that there is no need for any iterative procedure for deigning the PID controller. The validity of the proposed approach is carried out by checking robustness and optimality. The results are compared with the recently proposed standard soft computing methods. In this work, the sun tracking system with DC servo motor and PID controller is shown in Figure 3 & Figure 4. In order to harness the maximum efficiency from the solar panel, at least two-axis sun tracking is required, i.e. one is azimuth angle (θ) which measures the angle of incoming sunlight on the surface of the PV cell and the other is the titled angle (α) which measures the inclination angle of sunlight.

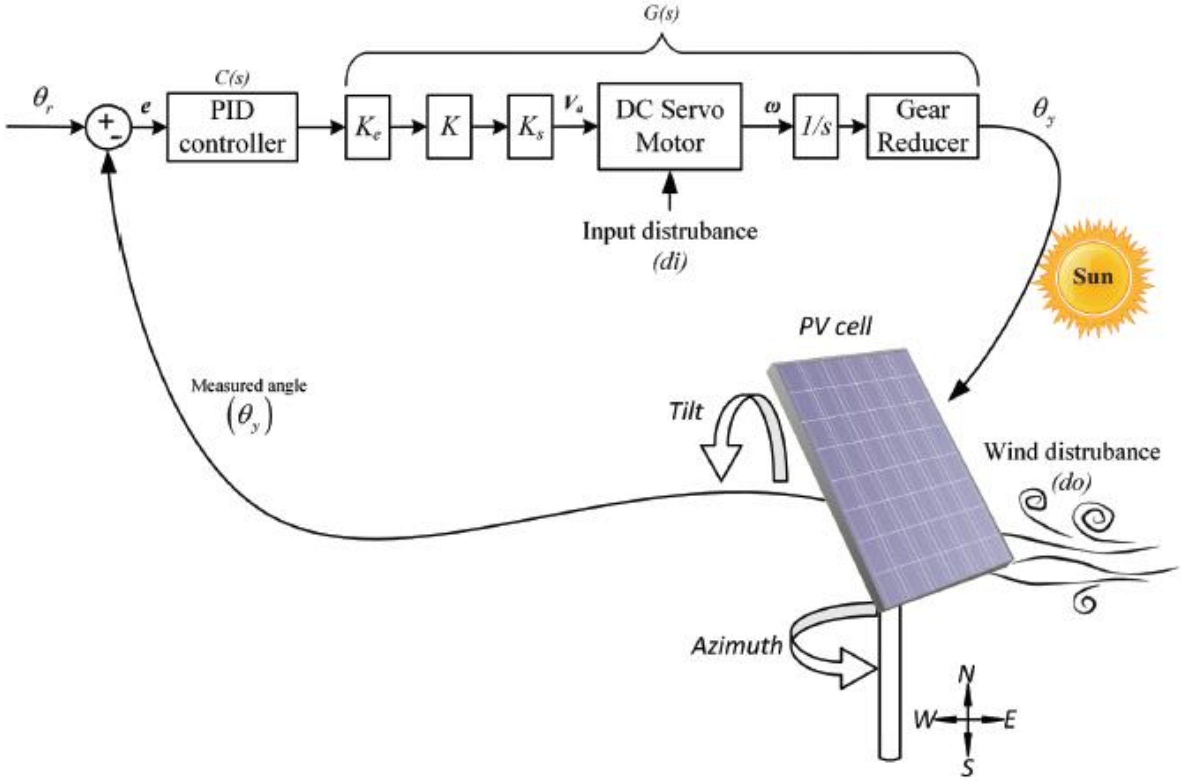

Figure 3: Control of sun tracker system layout [4].

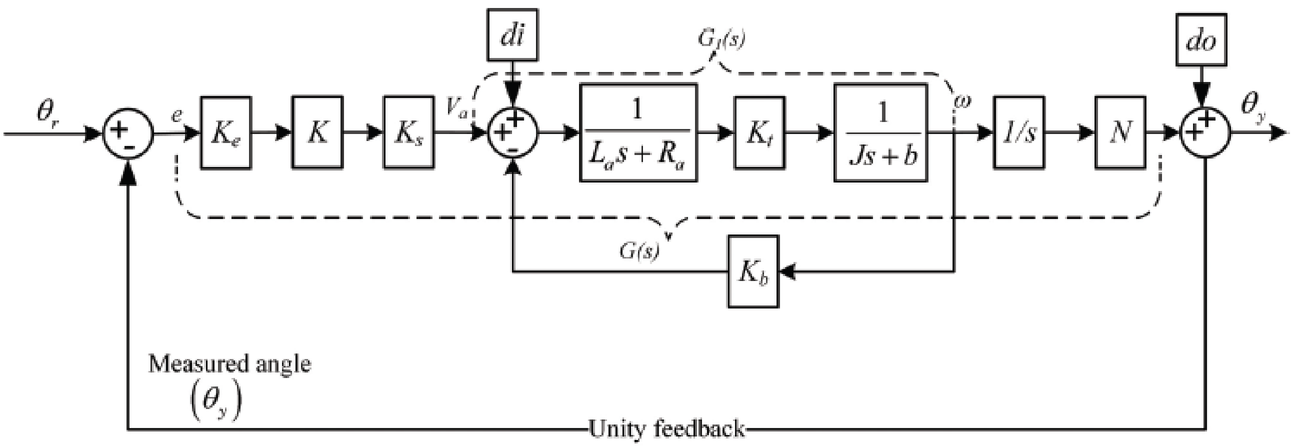

Figure 4: Control of sun tracker system layout [4]

5. Results and Discussion

5.1 Time Response & Analysis

To validate the proposed technique and to show the advantage of the QRAWCP approach, the step response of the sun tracking system has been analyzed for three cases, (i) without disturbance, (ii) with input disturbance, and (iii) with output disturbance. The results have been compared with the recently designed PID controller for the sun tracking system which is based on swarm optimization approaches such as PSO [5], FFA [5] and CSA [5]. The PID parameters of the proposed QRAWCP PID, PSO PID, FFA PID and CSA PID are given in Table 2. The performance of the proposed ID controller and other existing PID controllers is presented in case (i), case (ii) and case (iii) for without disturbance, with input disturbance and with output disturbance, respectively.

Table 2: PID controller parameters

Method	K_p	K_i	K_d
QRAWCP PID (Proposed)	2621.8	5.6443	111.721
PSO PID	9.51202	7.49203	0.00022
FFA PID	9.72083	7.44047	0.0001
CSA PID	9.99999	8.11378	0.0001

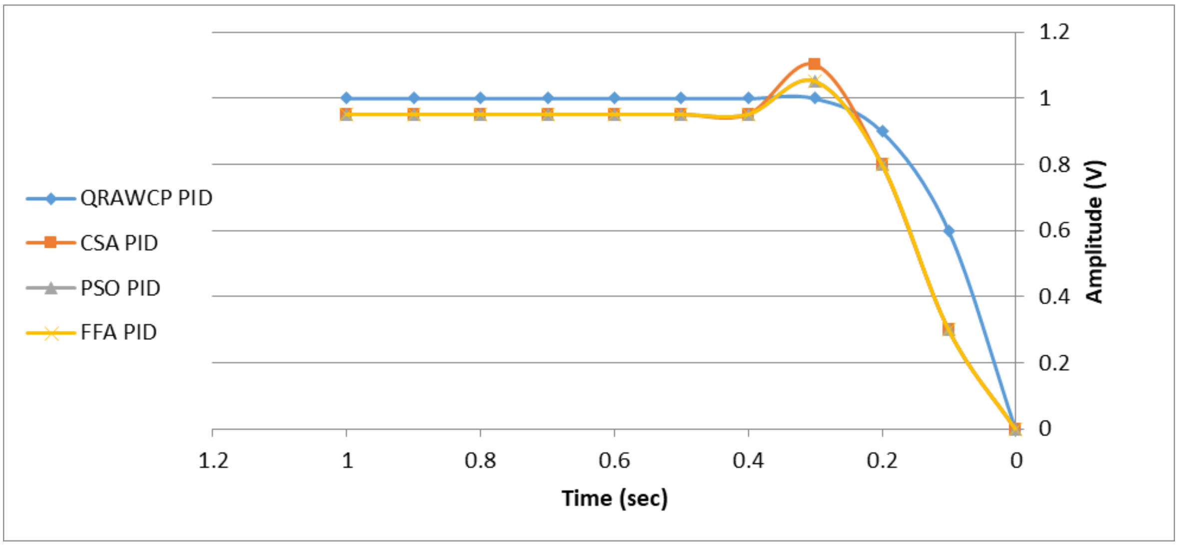

Figure 6: Step response of system with PID controllers

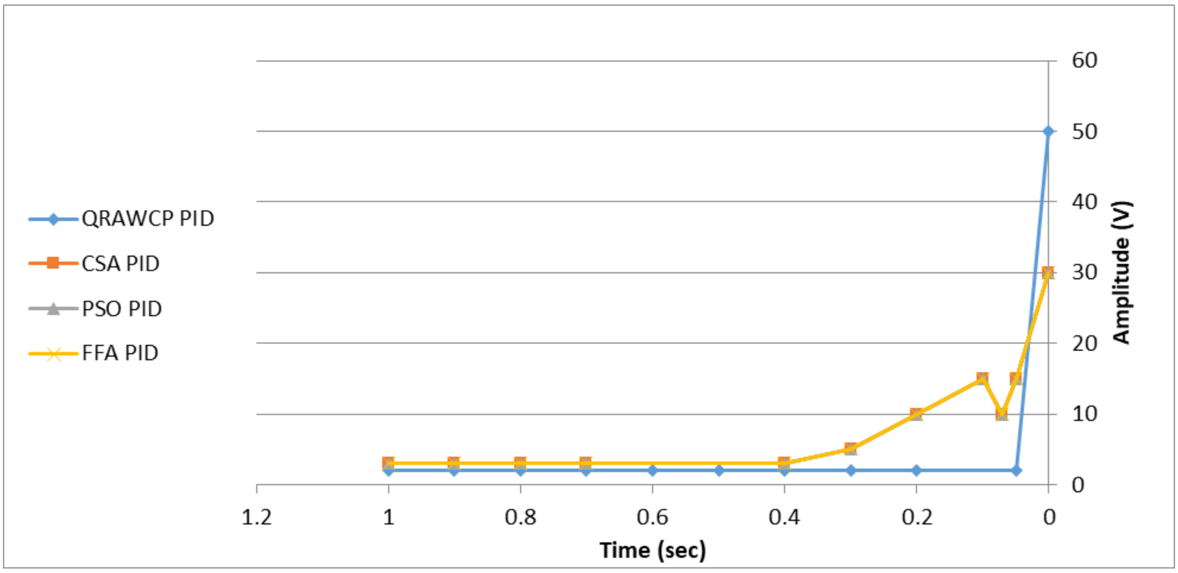

Figure 7: Control input response without disturbance.

5.2 Parametric Uncertainties

It is a known fact that in real time the parameters of the system are not constant. They fluctuate between a minimum and a maximum value, and this is primarily due to non-linearity, environmental change and also due to aging. The main objective of any controller design is that it should work even though uncertainties exist in the system. In our case, for the sun tracker system model, the performance analysis is carried out for both lower and upper bounds. In Figures 8 & 9, it is observed that the performance of the proposed controller is better in comparison to existing controllers except control input is slightly more at early part of the response.

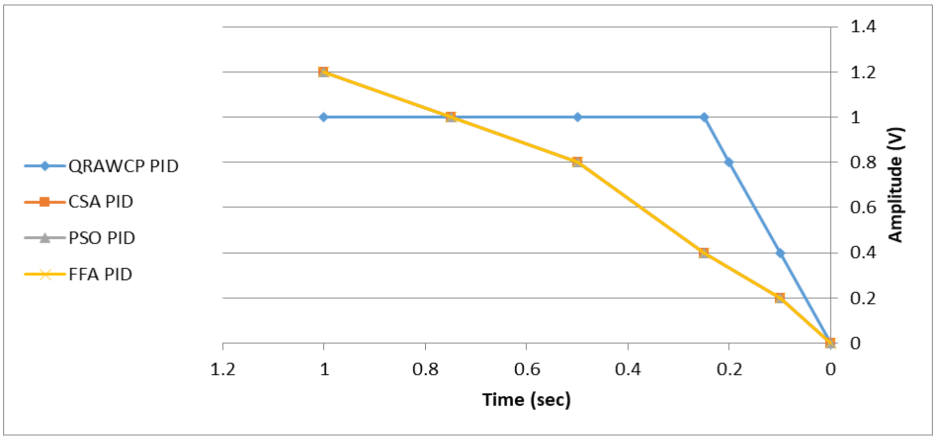

Figure 8: Response for 50% parametric uncertainties in system without disturbances (Lower Bound)

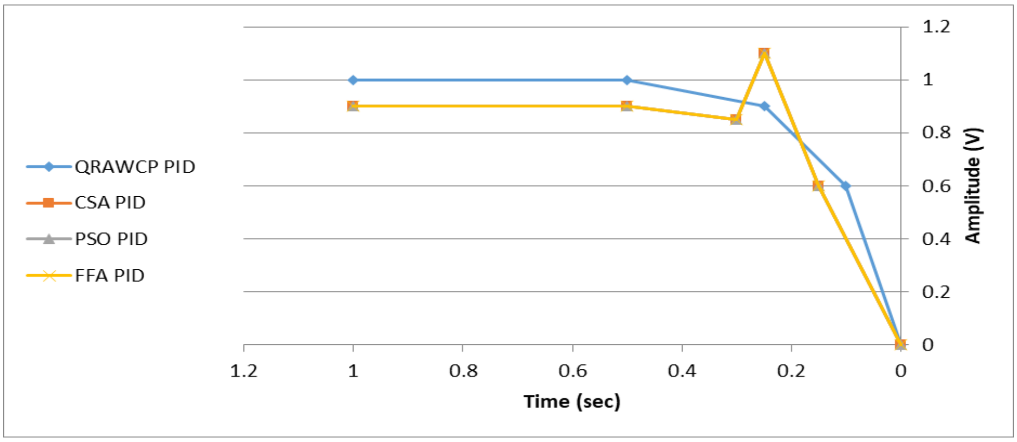

Figure 9: Response for 50% parametric uncertainties in system without disturbances (Upper Bound)

6. Conclusions

This work deals with the direct formula for designing an optimal PID controller for sun tracking systems without using iterative and time consuming processes. In this regard, new QRAWCP approach is proposed for tuning PID controller. It is shown that the proposed technique gives improved performances for sun tracking system in comparison with recent stochastic optimization methods such as PSO, FFA and CSA in terms of transient response, loop robustness and integral error performance indices.

The main objective of this paper is to indicate that in PID controller design applications, particularly for sun tracking systems, there is no need to reuse recently developed, time consuming, soft computing techniques for PID controller design of sun tracking systems. Still, the results are based on fundamental control theory which is suitable for designing PID controller. For future work, the proposed approach can be applied on various other engineering problems. It is vital to put into prospective the fact that the work is still in progress for developing the direct formula for finding the optimal controller when there is parametric variations in the sun tracking system.

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