Chapter 10
Development of an Advanced Solar Tracking Energy System

Samuel Davies, Sivagunalan Sivanathan, Ewen Constant, and Kary Thanapalan

Abstract This paper describes the design of an advanced solar tracking system development that can be deployed for a range of applications. The work focused on the design and implementation of an advanced solar tracking system that follow the trajectory of the sun's path to maximise the power capacity generated by the solar panel. The design concept focussed on reliability, cost effectiveness, and scalability. System performance is of course a key issue and is at the heart of influencing the hardware, software and mechanical design. The result ensured a better system performance achieved. Stability issues were also addressed, in relation to optimisation and reliability. The paper details the physical tracker device developed as a prototype, as well as the proposed advanced control system for optimising the tracking.

Keywords Solar tracker · Physical design · Controller design · Stability · Optimisation

10.1 Introduction

Increased efforts in decarbonising the air includes the use of renewables, and coal's contribution to UK's energy capacity demands falling from 4% (2018) to just 2.8% (2019) is further confirmation of its downward trend. This is just one example of the effects that political decisions and commitments are having on our basket of energy sources contributing to the grid. The global uptake in renewables has incentivised research and development in energy capture, storage and application [1, 2]. The Solar Photovoltaic systems is one such technology that has grown vastly in its research and application [2]. UK alone has seen a growth of over 13 GW capacity in solar PV with deployment ranging from 4 KW to over 25 MW [3]. This paper focuses on optimising the Solar PV performance with respect to its power capacity output, and this is achieved through designing a tracker controller. The tracking system proposed here aims to verify and build upon other research efforts made in this field [4].

S. Davies · S. Sivanathan · E. Constant · K. Thanapalan (✉)
Faculty of Computing, Engineering and Science, University of South Wales, Pontypridd, UK
e-mail: Kary.thanapalan@southwales.ac.uk

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Whilst sub 4 KW systems make up over 90% of the number of installations in the first quarter of 2020 in the UK, it only amounts to 20% of overall capacity installed. The majority of the capacity is made up of installations greater than 5 MW [3]. Further research at the University of South Wales therefore hopes to apply the findings published in this paper to investigate the feasibility of deploying on a larger scale. This involves testing suitable methods of accomplishing a reliable way to monitor the production, and to balance the gains against the fact that we are now proposing to introduce moving parts into what is otherwise a mechanically advantageous static system. The tracking needs to increase the overall yield to be worthwhile, thus complementing the greater decarbonising effect of deploying on a larger scale.

10.2 System Configuration

Tracking the sun's path is one of the efficient measures that may be adopted to improve the panel performance. Several researchers have investigated many different tracking mechanisms [4, 5]. The physical solar tracking system construction (Fig. 10.1a, b) and its system performance depended on the choice of hardware, firmware and mechanical operation of the system. The system configuration described here is therefore with reference to its mechanical operation, and its hardware and firmware design. Initially a small-scale prototype system is investigated to serve as a proof-of-concept.

Mechanical operation of the system is designed to have the flexibility to rotate more than 270º azimuth, and ~90º in elevation. The stepper motor and the linear servo actuator are straight forward in their operation, but the linear actuator position should be designed carefully in order to achieve the maximum elevation of 90º.

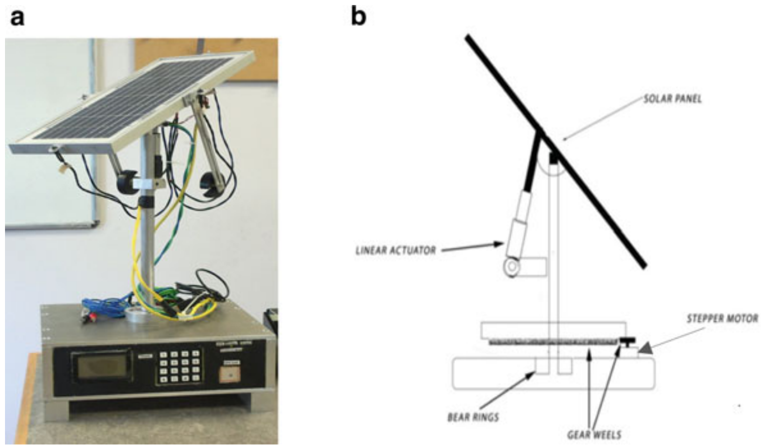

Fig. 10.1 **a**. Physical prototype-built. **b**. Mechanical model of the solar tracking system

The design was calculated taking into consideration the arrangement of suitable components which had been selected with reference to cost and performances. The design specification in this case was to achieve 90º in elevation. It was preferred to have a box arrangement under the mechanical system rather than leaving the base as plane metal. This improves the stability of the structure and secures some hardware components to sit within the box arrangement.

The hardware design of the system is mainly based on the M16C/62P microcontroller which improves system stability. Rotating mechanism is simplified in this work and the operation is simply interfaced to the Micro Controller Unit (MCU) using the most widely available and cost effective components in the market. This helps reduce the cost of the overall system prototype and better prepares this product for manufacturing. The solar tracker includes a microcontroller, and so firmware design is also an essential part of this system. Two possible design process was investigated in this work. They are firmware design for the microcontroller, and PC interface design [5]. The firmware design is a critical part of this system design and all the MCU configurations are reference to the datasheet of the M16C/62P. C language has been used to develop both Firmware for the MCU and Lab windows CVI 2010. Lab windows CVI has been used to develop the PC user interface development which based development environment offered by the National Instrument. The MCU firmware development structures are based on the state machine design adopted to superloop architecture. Each state is treated as separate functionality modules and can perform different functions until the state is changed or navigated through.

The remainder of this paper will describe the computer-based model developed to represent the small-scale solar tracking prototype already described (Fig. 10.1a, b). This model provides the basis for future math-based design, analysis and controller design of solar tracking energy system, to be applied for various applications including large scale deployment. The block diagram (Fig. 10.2) represent the solar tracker model, developed in MATLAB/Simulink™. The system has been developed from first principles for both the motor torque and the panel positioning. Panel weight and size, along with motor parameters, were selected to match as closely as possible

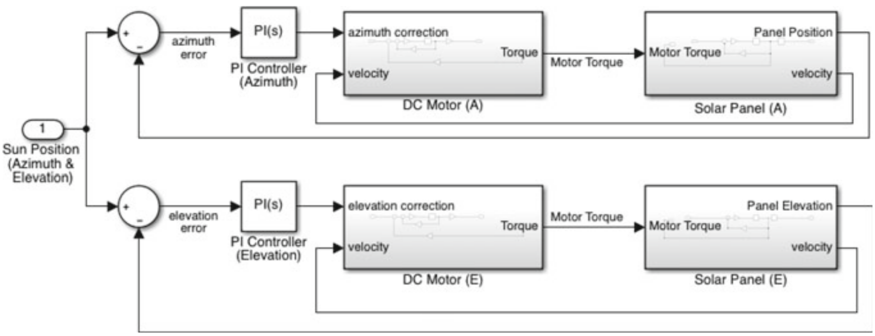

Fig. 10.2 Solar tracker system model

that of the physical prototype (Fig. 10.1a, b). The tracker system model receives a series of small step inputs representing the sun's azimuth and elevation path for the University's longitude and latitude, −3.33 and 51.59 respectively, for the complete year of 2020.

The system has poles that lie at the origin of the complex s-plane, but the feedback results in the torque output curve resembling an impulse response fed into the panel positioning, thus ensuring a stable system over all. The controller improves the system performance and serves to protect the motor's longevity over time by eliminating the otherwise overshoot during each step positioning update.

10.3 Controller Design

The target of the tracking control strategy is to develop a simple, but effective control method to obtain the desired positioning output with reference to sun position. This will ensure improved power capacity outputs. For simplicity and demonstration purpose a simple P-I (proportional integral) controller design was implemented (Fig. 10.2). A P-I controller is widely used in industrial control applications to regulate system variables. P-I controllers use a control loop feedback mechanism to control system variables and are both accurate and stable controllers. Without the controller at all, the system (Fig. 10.2.) is not responsive enough and has too large a settling time to cope with the physical dimensions modelled. The tuned controller on the other hand improves the settling time to under one second and does so without adding an overshoot or steady state error. The fourth-order system behaves in effect as a first-order system with the controller in place. Note, a differential term is not required due to there being no sudden changes on the input representing the sun's path, and so a two-term controller is sufficient in this case. The university is currently developing the system further so to be able to investigate the potential advantage of tracking stronger irradiance that may not always be on the sun's path. The controller in this case will need to be adapted to cope with more sudden changes with larger step movements.

10.4 Results and Discussion

Extensive research has concluded how tracking can improve the annual yield of a solar panel, and the proposed system here will look to further build on these results. The transfer function (1) for tracking the azimuth plane in Fig. 10.2 is shown below, where kd represent the damping constant, J the motor inertia, kf the back emf, kt the torque constant, L the motor inductance, and R the motor resistance.

$$\frac{ki}{s^4(R/L + kd/J)s^3(R * kd/L * J)s^2 + kp \cdot s + ki} \tag{10.1}$$

A comparison (Fig. 10.3a) of the system with and without the controller in place highlights the benefit of the controller. The step input represents a single elevation update of the panel. The controller dramatically improves the response rise time (s) and settling time (s), and does so without overshoot. This is even more critical if one wishes to update the panel position more frequently (e.g. each minute rather than hourly) as the panel elevation position may not have settled in time before receiving the next step input. The system is able to handle step inputs as frequent as 10 s intervals with the controller in place; evident in Fig. 10.3a. Of course, it is unnecessary to track the slow moving sun path so frequently.

A one-day snap-shot (Fig. 10.3b) serves as an example showing how the panel position successfully tracks the sun's path with accuracy. Here, the x-axis represent the time(s) from sunrise to sunset, and the y-axis represent the elevation in radians. The controller also tracks the sun's azimuth plane (Fig. 10.3c) as reliably as it does the sun's elevation, again over the same sun rise to sunset duration. The sun's azimuth is also recorded in radians, whereby 0 degrees radians in represents North. Based on the initial results collected to date, it is worth considering the impacts of scaling up this system. Several advantages and incentives will be further investigated, such as monetary gains from maximising governmental subsidies for on-grid applications,

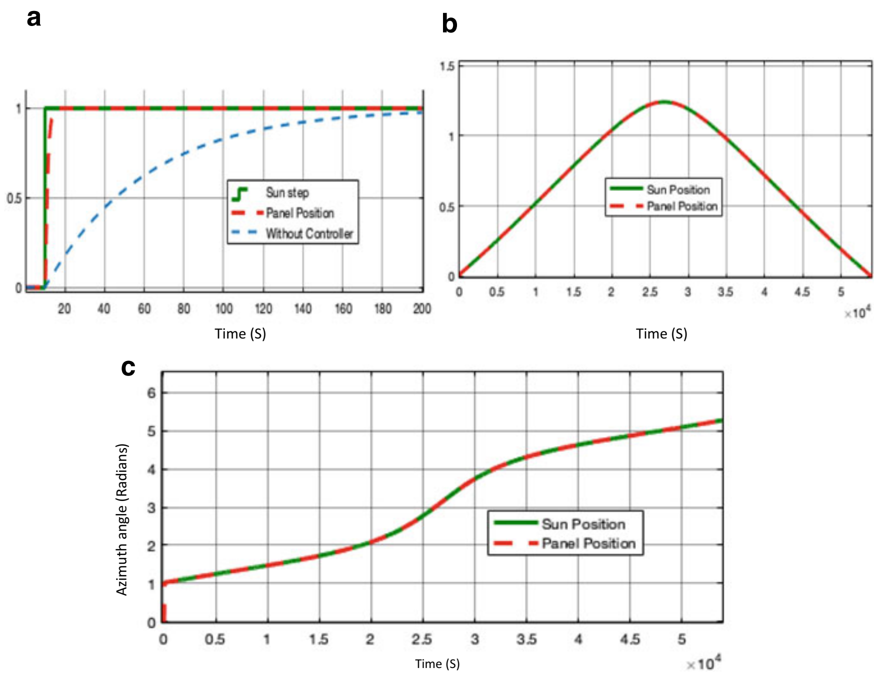

Fig. 10.3 **a**. Positioning with and without a controller. **b**. Controller tracking the Sun's elevation. **c** Controller tracking the Sun's azimuth plane

and technical gains in improving battery utilisation and battery sizing for on off-grid applications. There is also the environmental benefit in improving the carbon footprint, especially if scaled up to the larger solar farms.

10.5 Conclusion

The paper describes a possible solar tracking system that helps improve the power capacity generated. Suitable combination of hardware, software and mechanical design were detailed, and the results indicated the potential improvement in performance with a PI designed controller in place. The system design attempts to limit the costs whilst allowing for scalability. It's also worth pointing out that the benefits should also apply to off-grid systems, as tracking provides a higher/broader daily energy output, thus better utilising the battery's capacity, and so allowing for a greater battery capacity to be installed.

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