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Development of Cloud Movement Prediction Method for Solar Photovoltaic System

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Abstract: Variability of power generation due to the prevalence of cloud cover over solar photovoltaics (PV) power plants is a challenge faced by grid operators and independent system operators (ISOs) in the integration of solar energy into the grid. Solar forecasts generated through ground-based sky imaging systems are useful for short-term cloud motion predictions. However, the cost of sky imaging systems currently available in industries is relatively high. Hence, a ground-based camera system utilizing a simple webcam is proposed in this study. The proposed method can produce predictions with high levels of accuracy. Forecasts were generated through video analysis using MATLAB for the computation of cloud motion predictions. The image processing involved in the implementation of the proposed system is based on the detection of cloud regions in the form of a cluster of white pixels within individual frames and tracking their motion through comparison of subsequent frames. This study describes the techniques and processes used in the development of the proposed method, along with the evaluation of performance through analysis of the results. The predictions were carried out over multiple time horizons. The time horizons selected include 5, 10, 15, 20, 25, and 30 s. The overall results computed showed promising accuracy levels above 94.60%, which makes it adequate for generating reliable forecasts.

Keywords: forecast; solar photovoltaic; cloud cover; MATLAB

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0 Introduction

The demand for solar energy is predicted to escalate as more consumers and businesses are more aware of its benefits to the environment and economy[1]. Nevertheless, solar energy poses several economical and technical concerns surrounding its integration into the grid. These issues arise from factors such as frequent variability of solar irradiation, mismatch between supply and load profiles, high costs energy storage system, and the balance between grid flexibility and consistency[2-3].

Solar irradiation variability is caused by the presence of cloud covering over solar PV plants. The presence of cloud blocks the sun rays from reaching solar modules, which results in significant electricity production variations. Solar energy fluctuation produces transients in the grid that affects network voltage variability, consequently there is insufficient power to meet the momentary demand in the electrical grid[4-5]. Storing the energy could confront this issue, but energy storage technology costs remain high, making it an uneconomical solution. In addition, standby generators installed for mitigation during periods of high intermittency also adds to capital and operational costs of the solar PV plant[6].

There are two main types of solar forecasting: long-term forecast and short-term forecast. Long-term forecasts fall within horizons of several days and are typically useful for utilities and independent system operators (ISOs) for the purpose of unit commitment, scheduling, and improving power balance control performance[7]. Short-term forecasts, on the other

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hand, fall within the intra-hour range and are considerably helpful for power plant operations, balancing of the grid, real-time unit dispatching, automatic generation control as well as for trading[8-9]. Therefore, it is important to have reliable forecast information on the anticipated power production for efficient integration of PV plants.

Solar forecasting acts as an enabling tool for better integration of solar energy into the grid by significantly refining the quality of the energy injected into the grid and diminishing the operational costs of standby generators associated with meteorological dependence. Several methods have been proposed for the prediction of cloud motion. Numerical weather prediction (NWP) method is able to model large scale atmospheric motions well and provides forecast up to three to seven days. Nevertheless, NWP models are unable to predict the changes in cloud state, has limited capability in predicting smaller clouds and the cloud arrival time is only accurate up to several hours. For forecast timeframes of 3 to 4 hours, satellite cloud motion vector method is a useful alternative. However, this method is unfavorable for intra-hour forecasts and small-scale variability due to the lack of spatial and temporal resolutions. Both NWP and satellite imaging methods lack sufficient spatial and temporal resolutions to accurately predict the obstruction of the sun caused by clouds of small proportions. Moreover, NWP based statistical methods are also not capable of forecasting ramp events, causing the accuracy levels to falter during such situations[10-11]. The third method is sky imagery-based forecasts. This approach is good for short-term prediction due to its high spatial and temporal resolutions. Sky imagery-based forecasts deliver high temporal resolutions within a matter of seconds, high spatial resolutions within the span of a few meters, and rapid update rates in the matter of seconds. This is due to the fact that tracking clouds within the field view of a camera lens is able to provide a forecast of a certain cloud event shortly prior to its occurrence. Since most models of solar variability and solar irradiation requires cloud motion velocity as the main input, accurate cloud motion estimation is also essential for the intra-hour forecast of solar energy. This approach enables short-term forecast of the exact instant that the cloud shading of PV panels occurs. Cloud shading data allows the optimization of voltage regulation and better management of a microgrid[12-13].

An accurate short-term forecast is essential for distributed generation of electricity, power system planning, and operation that ultimately helps maintain grid stability[14-15]. In addition, grid connected PV plants are also subjected to violations of overvoltage limits. Short-term forecasting helps grid operators to prevent overvoltage problems and regulate the voltage optimally[16]. Ground-based pyranometer networks with cameras such as total sky imagers (TSI) can produce forecasts of high temporal and spatial resolutions. Nevertheless, these systems are extremely expensive. Therefore, a low-cost forecasting system that can produce reliable and accurate results is required[17].

Malaysia is located on the equatorial region, and subjected to tropical climate conditions that involve an abundance of sunlight throughout the year. However, these tropical climate conditions also mean that Malaysia would experience a higher percentage of frequent cloud cover compared with other countries that are away from the equatorial region. Therefore, solar photovoltaic plants undergo repeated fluctuations in power production, which leads to significant issues in grid integration. Due to high frequency of fluctuations, it is crucial to generate intra-hour forecasts that are capable of predicting output power over a short time horizon using more detailed information of short-term variability. This study aims to develop a ground-based cloud movement forecasting method to predict short-term cloud cover activity using sky-imagery based on weather conditions experienced in Malaysia. The method considers the dynamic nature of clouds movement in the sky to test the results' accuracy. Novelty of the proposed sky imagery based forecast method is in its cloud velocity estimation approach using webcam. The image processing involved in the implementation of the proposed system is based on the detection of cloud regions in the form of a clustered white pixels within individual frames and tracking their motion through comparison of subsequent frames. The coordinates of the cloud positions are calculated from video analysis, and the position of each cloud at a given time can be predicted using could velocity estimation approach.

1 Methodology

The proposed ground-based cloud movement forecasting method is based on a camera system with sufficient resolution and frame rate without filter to capture the motion of cloud movement. SEGi University grounds were chosen as the location for data collection due to the abundance of open-air areas that are suitable for capturing sky videos. The data collection stage involved recording cloud movement videos during daytime to be used for analysis. The recorded videos provided the actual arrival time of the clouds to check the accuracy of predicted forecast. The webcam used in this study is Logitech V-U0018 HD 720p (Table 1). This webcam is able to record videos in 720p resolution with a frame rate of 30 frames per second. It is important that a webcam with sufficient resolution is selected because videos with low resolutions or poor colour balance could result in images where the cloud and the sky are difficult to be differentiated thus leading to significant error in the forecast.

Table 1 Data needed to calculate projected area captured by camera

Model	Focal length (mm)	View angle (°)	Aspect ratio
Logitech V-U0018 HD 720p	4.0	60	35.88

Cloud motion prediction was carried out by analysing images through programming performed in MATLAB. The output is an accurate estimation in arrival time of cloud regions over a time horizon. As clouds move towards the direction of the solar PV plant, the system automatically detected and computed an estimated cloud arrival time. The videos were fed into the system at intervals of 30 s, and the system generated forecasts over a 0−15 min time horizon.

The process of video analysis is shown in Fig. 1. Instead of a live stream, pre-recorded videos of 30 s were analysed at different times of the day for testing purposes. This involved segmenting the collected videos into a sequence of frames, and then identifying the cloud regions of each frame. In Fig. 2, a sample frame was extracted from the input video. Then the change in position of said cloud region in each subsequent frame was analysed to determine the speed value. The speed value was then used to find the arrival time across a distance, thus enabling cloud motion prediction. MATLAB was utilized as the software platform to create forecasts using the images recorded by the webcam.

The single frame was acquired by using the ‘step’ function. Cloud components of this frame were then extracted out of all three red, green, and blue layers by using two threshold values of 0.45 and 1.00, defined at the initialization portion of the script. The second threshold, 1.00, was defined to eliminate over saturated pixels that might represent glare. The white components extracted under the second threshold value was then subtracted from the image formed using the first threshold for each layer. All three layers of red, green, and blue were then combined to form a common white cloud region, which produced a binary image (Fig. 3).

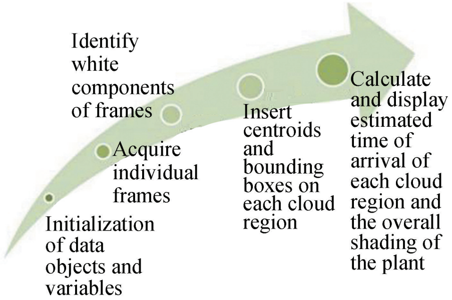

Fig.1 The process of video analysis

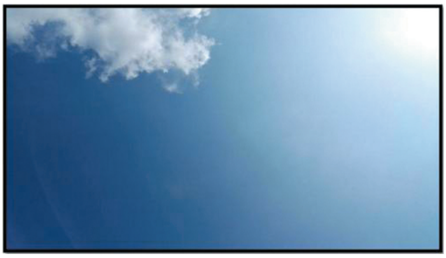

Fig.2 Individual frame extracted from the input video

Fig.3 Common white components regions of red, green and blue layers

The binary image was subsequently put through a 2-D median filter denoted by ‘medfilt2’, which carried out a non-linear operation simultaneously reducing noise and preserving the edges. Blob analysis was then applied to the binary image, to group the connected white pixels of the frame to identify cloud regions. In addition, the blob analysis function set the area, centroid, and bounding box coordinates of the cloud regions. A bounding box was then inserted around each cloud region with corresponding centroid coordinates (Fig. 4).

Fig.4 RGB frame with bounding box and centroid

The final step is calculating the time of arrival for each cloud region. The horizontal displacement of the centroid as compared with its initial position was determined and denoted by '*x*Displacement'. This displacement was used to calculate the velocity of each cloud region by dividing it by the time at that given frame. To calculate the estimated time of arrival, *x*-coordinates of the front edge of the bounding boxes surrounding each cloud region can be used instead of the centroid, as this front edge will reach the solar plant earlier. Using the centroid to calculate estimated time of arrival is inaccurate for large cloud size. As a result, the estimated time of arrival was obtained by dividing the distance to reach the solar plant with the velocity obtained.

2 Results and Discussion

The videos captured included cloud movement gathered under three main conditions: clear, moderate, and overcast skies. The data with cloud cover below 10% was categorized as nearly clear sky conditions. The moderate skies produced cloud cover of more than 10% but less than 50%, while anything above that was categorized as data gathered under overcast skies. A collection of data was gathered over the course of two weeks. In Malaysia, moderate and cloudy skies are more prevalent due to the tropical conditions. Moderate skies with an abundance of cumulus and stratocumulus clouds are easier to track.

The performance evaluation of the proposed cloud motion prediction system was assessed through the testing of one main parameter, the projected position of cloud region over a selected time horizon. The projected position of each cloud region was forecasted by predicting the coordinates of the said cloud region over a time horizon. The forecasted cloud positions can be compared with actual results obtained from the recorded videos.

For example, Fig. 5 shows the initial cloud position at $t = t_0$, identified by a bounding box with its centroid labelled clearly. The prediction of the cloud position at the selected time horizon of 20 s was computed in relative to this initial position. Fig. 6 illustrates the predicted position, indicated by the shifted bounding box and coordinates. The original position is shown in dotted lines for comparison. On the other hand, Fig. 7 represents the actual position of cloud region in a frame extracted at $t = t_0 + 20$ from the collected video.

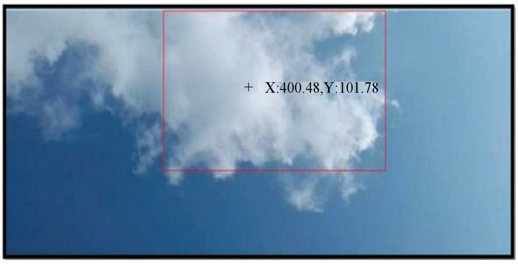

Fig.5 Position of cloud region at $t = t_0$

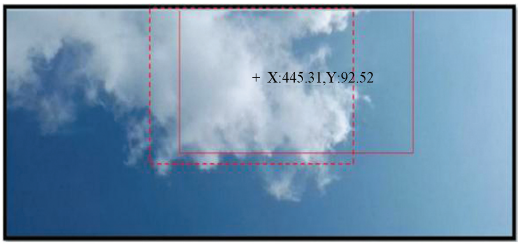

Fig.6 Predicted position of cloud region at $t = t_0 + 20$ (The dotted line represents the position of cloud region at $t = t_0$ for comparison)

Fig.7 Actual position of cloud region at $t = t_0 + 20$

A total of 48 samples data were gathered. Eight samples were collected for each of the six time horizons, namely, four samples of clear skies, two samples of moderate skies, and two samples of overcast skies. The predictions were carried out over multiple time horizons. The time horizons selected include 5, 10, 15, 20, 25, and 30 s. To analyse the accuracy of the forecast method, a chart was generated based on the average of the eight samples obtained for each time horizon (Fig. 8). Accuracy is defined as

$$\text{Accuracy} = \frac{\text{Actual position}}{\text{Predicte dposition}} \times 100\%$$

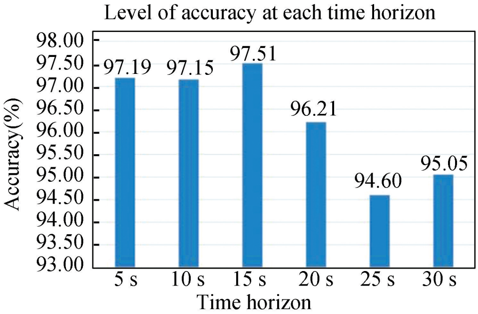

Fig.8 Accuracy of forecasts for data evaluated at each time horizon

3 Conclusions

One of the greatest challenges for integrating solar energy into the grid is the variability of solar irradiation due to cloud cover. Grid operator should have knowledge of the presence of cloud cover over a solar PV plant to carry out measures to compensate for the loss of power. The best way to achieve this is through solar forecasting. Due to the varying nature of cloud cover in Malaysia owing to its location at the equatorial region, a short-term forecasting method that utilizes a ground-based camera system was adopted. In the hopes of making the system economical, a simple webcam was adopted in this study. The primary focus is the development of a cloud movement prediction method for application in solar PV plant.

MATLAB was selected to be the software platform for video analysis. The image processing involved in the implementation of the proposed method is based on the detection of cloud regions in the form of a clustered white pixels within individual frames obtained and tracking their motion through comparison of each subsequent frames. The predictions were carried out over multiple time horizons. The time horizons selected include 5, 10, 15, 20, 25, and 30 s. The accuracy of the forecasted results compared with actual results were obtained within the range of 94.60% to 97.51%. Only the horizontal motion or the prediction of the x-coordinates were included in this study, as the horizontal movement had the biggest impact on the forecasting process and the vertical motion or the y-coordinates showed negligible variations in value.

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