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Intra-hour cloud movement detection for solar forecasts based on ground imaging system

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The penetration of solar energy continues to rise and becomes a central piece of the global energy mix. Thus, considering ways for more efficiently operated power systems to accommodate significant amounts of such a variable resource will be increasingly important. Improvements in solar forecasting methods and techniques will clearly be relevant. In addition to season and irradiation angle, the most important factor of influencing solar energy output is the effect of cloud movement on solar irradiation shadow on solar plate. This paper briefly analyzes the advantages and disadvantages of various moving target algorithms, and compares the typical feature matching algorithm (block motion estimation algorithm) and optical flow algorithm (CLG algorithm) against the collected cloud movement image sequence. The result shows that optical flow algorithm (CLG algorithm) is applied to cloud movement image. The calculation is very fast, with an accuracy above 96%. A comparison with CLG algorithm shows that direction and speed accuracy of block motion estimation algorithm based on hexagonal search pattern is 0.79 and 0.47, respectively.

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1. Introduction

Global demand for renewable energy integration in the power grids emphasizes the importance of economic and technological issues. Solar energy is more evenly distributed across the world than are other forms of renewable energies, such as wind or hydroelectric power. Where wind and hydro energies are available, they are good sources of energy. However, only select places are prone to good wind, and hydro can have many adverse impacts on the environment. By contrast, solar energy is spread out across the world, and has very little environmental impacts[1].

Photovoltaic systems (PV) are very modular; such a system can be installed as a large or a small system depending on need. For example, one can install a PV module in each classroom for lighting, put PV power at a gate to run a motorized gate-opener, set it on a light pole for street lighting, or place a PV system on a house or a building and supply as much energy as wanted. A small budget can be allocated in the first year of PV use, and more modules and batteries can be added later when more comfortable with solar or when loads increase. New PV modules can be added at any time.

When PV penetrates into the power grid, some concerns require attention. These concerns arise from the variable nature of the solar resource, seasonal deviations in production and load profiles, high cost of energy storage, and the balance between grid flexibility and reliability [2,3]. Thus, solar plants are often backed by ancillary generators for periods of high

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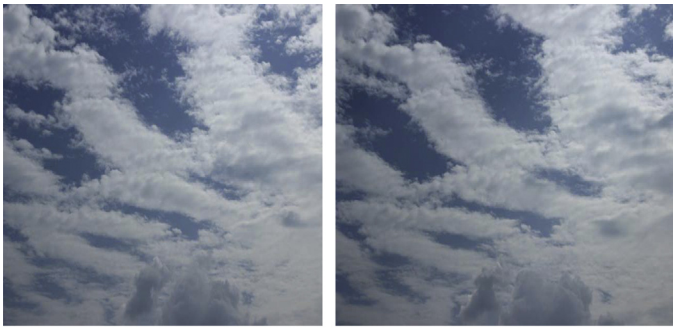

(a) (b)

Fig. 1. (a)(b) Cloud movement images collected via ground imaging system, Size of 3456 × 5184, collecting interval of 5 min.

variability, which increase the capital and operational costs of solar generation. Accurate solar forecasts over several time horizons are required so that Independent System Operators (ISOs) or equivalent grid-balancing authorities and successfully integrate increased levels of solar power production while maintaining reliability [4–6]. As solar penetration grows, solar forecasts on multiple time horizons become increasingly important for grid regulation, load-following production, power scheduling, and unit commitment. Short-term, intra-hour solar forecasts are particularly useful for power plant operations, grid balancing, real-time unit dispatching, automatic generation control (AGC), and trading.

Both numerical weather prediction (NWP) and satellite imaging techniques lack the spatial and temporal resolution to provide information on high frequency fluctuations of solar irradiance. An alternative method is provided by a ground-based imaging system for local meteorological conditions. To predict solar farm power output, the following steps must be followed: first, modeling of solar panel with variables of shading effect and sun irradiance. Second is using imaging to predict the movement of the cloud. Third, relationships must be found between the cloud motion and shading, as well as sun irradiance, for each panel. Finally, combine all other facts (e.g., rotation of the sun) to predict the output power. Cloud movement detection is used to determine the direction and relative velocity of each segment between two continuous frames. In this paper, we proposed a ground-based imaging system to predict cloud movement.

2. Moving target detection method

To forecast the direction and speed of cloud movement, ground image acquisition equipment should be used to conduct image collection of the sky, as well as moving target detection of the collected cloud images. Motion image analysis methods can be concluded into three types: image gray matching method, feature matching method, and optical flow method. Image gray matching method [7,8] is simple, but its running speed is highly slow. Feature matching method [9–11] with excellent noise immunity is applied to long-term heavy load processing. However, feature extraction and establishment of corresponding relation are may be difficult. The advantages of optical flow method [12] are as follows: optical flow not only contains motion information of objects being observed, but also carries rich information about 3D structure of scenery. Therefore, optical flow method is important in motion image analysis. So-called optical flow refers to the speed of mode motion in the image. It is a type of 2D instantaneous velocity field. The 2D velocity vector is the projection of 3D velocity vector of visible point in scenery. Optical flow is widely used in object segmentation, recognition, track, robot navigation, recovery of form information, and other important fields [13].

3. Optical flow method

Since Horn and Schunck [14] developed a pioneering method related to optical flow in 1981, many scholars have followed, including optical flow by Lucas and Kanade [16], CLG [17], warping method [18], and phase method [19]. In order to classify and evaluate optical flow method, Barron [21], Galvin and McCane [14,20], Weickert [4], and Papenberg [17] have compared typical optical flow algorithms. By combining these papers, optical flow algorithms can be divided into four categories: differential-based methods, region matching, transformation-based methods, and phase-based methods. Among these methods, differential-based methods have been widely used because of better performance and relatively simple process. Differential optical flow techniques develop optical flow solution via differentiation. Based on the basic equation of optical flow, this technique can obtain dense solution of optical flow iteratively by adding certain constraints. The concept of optical flow was proposed early, but optical flow has been developed as a technique after the establishment of differential optical flow technology.

The advantages of differential-based optical flow technology are embodied in three aspects. First, it uses a strong mathematical theory as its foundation. Optical flow technology is an ill-posed problem, which cannot be solved in isolation from powerful mathematical tools. Differential optical flow technology represents a link between optical flow and mathematics. Secondly, its solving accuracy is high. Differential optical flow can obtain higher estimation accuracy via relaxation itera-

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