Design and Construction of an Internet of Things-Based Soiling Potential Monitoring System on Solar Panels Using Environmental Parameters

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ABSTRACT

Soiling is the accumulation of dust and particles on the surface of solar panels, which reduces the intensity of solar radiation reaching the photovoltaic module and thereby lowers the output of a solar power plant (PLTS). This research designs and tests an Internet of Things (IoT)-based soiling potential monitoring system, evaluates the accuracy of the environmental sensors used, tests the performance of the IoT system's data communication, and produces a real-time estimate of soiling potential from environmental parameters. The system was built on an ESP32 microcontroller integrated with a GP2Y1010AUF dust sensor, a DHT22 temperature and humidity sensor, a tipping-bucket rainfall sensor, an LM393 wind speed sensor, and an AS5600 wind direction sensor; measurement data was sent via the MQTT protocol to HiveMQ Cloud and displayed on a Microsoft Visual Studio-based Graphical User Interface (GUI). Communication testing showed 999 data packets delivered with zero loss (100% delivery rate), indicating a transmission link reliable enough for continuous monitoring. Sensor accuracy varied sharply across components: the DHT22 produced an average relative error of 0.73% for temperature and 10.55% for humidity, the rainfall sensor showed a standard deviation of 0.76–2.58 mm across repeated trials, and the AS5600 wind direction sensor performed stably throughout testing, while the GP2Y1010AUF dust sensor saturated at high concentrations with a maximum reading limit of 640 μg/m³ and the LM393 wind speed sensor recorded an average relative error of 40.44%, well above a dependable threshold. Based on the environmental data obtained, the system produced a qualitative estimate of soiling potential using a rule-based approach that grouped conditions into low, medium, and high categories; testing showed that rising dust concentration combined with the absence of rain raised the soiling estimate, while rainfall lowered it. This estimate has not been validated against direct measurement of soiling ratio or dust mass on the panel surface, so it remains indicative rather than quantitative. This study shows that the developed system can support real-time environmental monitoring while providing an early indicator of soiling potential as a basis for determining the timing of solar panel inspections and cleaning, provided further calibration is applied to the wind speed sensor and a wider-range dust sensor is used in future work.

Keywords: Internet of Things, solar panels, soiling potential, real-time monitoring, MQTT, ESP32.