Smart Automation for Solar Panel's Efficiency Optimization: A Step Towards Sustainable Energy in Bangladesh

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Abstract

The whole world is shifting towards renewable energy where solar panel produces 20% of it. However, solar panels' efficiency decreases in real time due to overheating and dust build-up on the surface. Heating of panels under direct sunlight decreases voltage, increases resistance, leading to lower power output. Overheating gradually causes panel degradation. Due to this, over 4.6 billion USD is lost each year. In Bangladesh, off-grid solar panels provide electricity to more than 20 million people. Such inefficiency hampers the popularity and sustainability of this renewable energy source to a vast population of Bangladesh. There is a term called solar panel temperature coefficient, which is a measure of how efficiency changes with temperature. For example, solar panels can lose 0.5% efficiency per 1 degree celsius increase in panel temperature where the ideal temperature is considered 25 degree celsius. Suppose on a hot day, a 1000W rated solar panel with -0.5%/°C temperature coefficient reaches 50°C. For that, The temperature difference is 50°C – 25°C = 25°C and the power loss percentage is 25°C x 0.5%/°C = 12.5%. So, in this case, at 50°C, power loss in watts, 1000W x 12.5% = 125W and the solar panel's adjusted power output would be 1000W – 125W = 875W. We developed a convenient solution, an automated solar panel water cooling device, using an IoT platform, water pump, temperature sensors, microcontroller, power supply, water reservoir, etc. It is programmed to ensure an optimal efficiency boost in harsh environmental conditions. Making water flow over the panel's surface for cooling purposes also cleans the panel surface. Our value-providing device aligns with Bangladesh's SDG goals. This research aims to make solar energy more viable and sustainable for the broader population. Prototype testing resulted in an average 20% efficiency boost per day.

Literature Review

Efficiency Challenges in Photovoltaics:

- Thermal Effects: Solar panels lose approximately 0.5% efficiency for every 1°C increase above the ideal 25°C. For instance, a panel at 50°C experiences around a 12.5% drop in power output.
- Soiling Impact: Dust and debris accumulation can block sunlight, reducing efficiency by up to 30–40% in some regions.
- Economic Losses: Global inefficiencies in solar panel performance cost over 4.6 billion USD annually.
- Automated Systems: Recent advancements in automated cleaning and cooling systems have shown promising results, including IoT-based solutions that boost efficiency by 20–30%

Research Objective

- Main Goal: Develop an integrated, automated water cooling and cleaning device to enhance solar panel efficiency under harsh environmental conditions.
- Specific Aims:
  - Reduce panel temperature via controlled water flow, thereby minimizing voltage drop and power loss.
  - Simultaneously clean the panel surface to remove dust and debris.
  - Use an IoT platform for real-time monitoring and automated control, ensuring optimal performance.
  - Align the solution with Bangladesh's sustainable development goals, improving energy access for over 20 million off-grid users.

Research Gap

- Fragmented Approaches: Current solutions address cleaning and cooling separately.
- Manual vs. Automated: Many existing cleaning methods are labor-intensive or inefficient in water use, and most cooling systems do not integrate real-time monitoring.
- Lack of Integration: There is a need for a combined system that optimizes thermal management and cleaning while enabling remote monitoring.
- Water Sustainability: Few systems integrate rainwater harvesting, critical in regions with limited water resources.

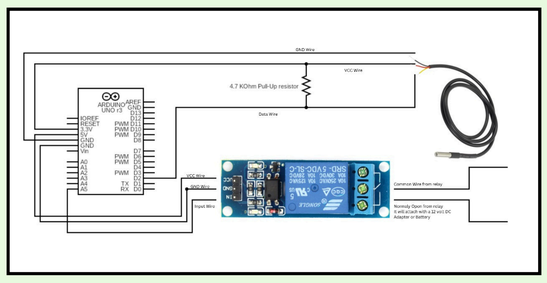

Fig-1: Diagram

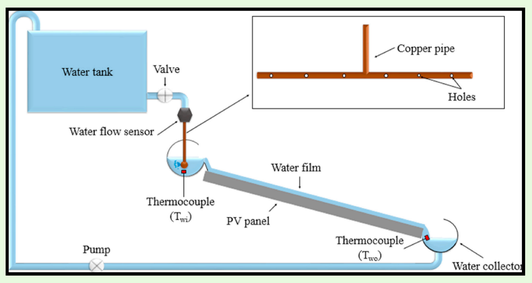

Fig-2: Diagram

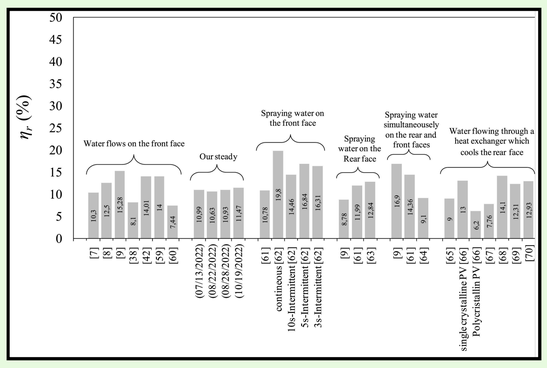

Fig-3: Data Visualization

Fig-4: Field Testing with cooling system

Proposed Methodology

1. System Design:
   - Integrate a tilted solar panel with a water reservoir, pump, and piping to create a uniform water flow over the panel.
   - Utilize the water flow for both cooling (reducing temperature by up to 25°C) and cleaning the surface.
   - Incorporate an automated rainwater collection mechanism to refill the reservoir, ensuring sustainable water usage.
2. Electronics & IoT Integration:
   - Deploy temperature sensors (e.g., thermocouples) and power sensors (voltage, current) to monitor panel performance.
   - Use a microcontroller to process data and trigger the water pump when temperatures exceed set thresholds.
   - Transmit data via mobile network to a user app for real-time remote monitoring.
   - Utilize power generated by the solar panel to run the control module, ensuring autonomous operation.
3. Prototype Testing:
   - System performance on a hot day using a 1000W panel showed average recovery of up to 125W, an average 20% efficiency boost.
4. Module design:
   - Parts used: Arduino Uno, Resistor, Water pump, DS18B20 temperature sensor, Wires, Relay module.
   - Measure temperature from the sensor every 5 minutes. Flows water for 3 minutes if high temperature is detected.
   - After flowing water once, module sleeps for 20 minutes.

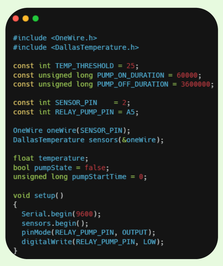

Fig-5: Code for module

Fig-6: Code for module

Fig-7: Field Experiment

Fig-8: Field Experiment

Conclusion

The integrated system improves solar panel efficiency by 20%, addressing overheating and soiling issues. It reduces global economic losses, enhances off-grid solar power sustainability in Bangladesh, and aligns with SDG goals by increasing reliability for over 20 million users. Future developments could enable broader adoption in similar regions.

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