IoT-Based Solar Energy for Rural Development: A Transformative Approach for Tribal Communities in Sathyamangalam Forest

P Sukumar[1], T M. Elamathi[2], S. Dhanish[3] and V. Manoj[4]
{sukumarwin@gmail.com[1], tmelamathi23@gmail.com[2], sdhanish080@gmail.com[3], manojkapildev3521@gmail.com[4]}

Professor, Department of Computer Science and Engineering, Nandha Engineering College (Autonomous), Erode, Tamil Nadu, India[1]
Department of Computer Science and Engineering, Nandha Engineering, College (Autonomous), Erode, Tamil Nadu, India[2, 3, 4]

Abstract. This project aims to assist tribal communities located in the Sathyamangalam Forest region through the installation of Internet of Things (IoT) based solar systems for sustainability and resilience. Smart solar panels and IoT based monitoring systems will provide continuous electrification to household residences, health centers and resource services, while at the same monitoring attributes such as solar panel voltage, battery voltage and household consumption. The technological aspects in the system will include environmental sensors that will monitor and notify on landslide and forest fire risk which will enhance community safety by providing advance notice in real time. It will also include intelligent fault detection and automatic control to sustain energy efficiency and appropriate lighting. The web-based dashboard's development phase will use PHP and XAMPP, which will allow it to compile information appropriately from solar panels, sensors and smart systems. The dashboard will display real-time monitoring of solar production, battery level and energy consumption, and will also provide streetlight monitoring (i.e., notify maintenance/hazards alerts). This project, through the investments made in renewable technology and smart solutions, will address energy access, environmental safety, and sustainable futures; it will also act as an implementation model of practice-based approaches for revitalizing communities.

Keywords: IoT based solar energy, smart solar PV, environmental monitoring, hazards detection, smart street lights, central dashboard, renewable energy, tribal empowerment, sustainability.

1 Introduction

In this work, the Internet of Things (IoT) based solar energy combined with real-time environmental monitoring (REM) technology approach is used to meet the requirement of the tribal people residing in Sathyamangalam Forest. This program not only ensures equitable access to the energy of the future, but also, by adopting next generation technologies, contributes to safety enhancement while also preparing for natural disasters. Environmentally benign energy is made available through smart solar panels to homes, clinics, and community centres. Every house can be monitored by the install addition IoT systems to record the energy used by the houses and the produced solar energy on site. The actual-time data set of solar

ICITSM-Part I 2025, April 28-29, Tiruchengode, India

DOI 10.4108/eai.28-4-2025.2357947

panel voltage, current power to the grid and battery status is displayed in a radial dashboard. It allows the administrators/residents to gain control over and monitor usage of energy judiciously and offers a sustainable power solution with efficient solar energy exploitation. As a precautionary measure against environmental hazards, a preparedness system has been established with the use of IoT sensor-based sensors for monitoring of landslides and forest fire. This type of sensors can be employed to measure the relevant critical parameters (e.g., soil displacement, temperature, gas emission (air quality), and so on. Alerts are automatically generated and reported in the web dashboard when limits are surpassed and the system is effective in terms of discharge (the discharging of the patient) and preventative measures by this type. This integration reduces the risk of accidents and lowers the death rate of natural disasters. Construction is performed using Internet-of-Things (IoT)-based smart streetlights strategically located in a given community. In this street light, the light intensity is varied based on the ambient light and the system also has failure detection method based on the automatic activation transfer learning, to achieve the reliability. They are used in order to optimize energy savings and to grant an extra level of security to the neighbourhood, i.e., mainly at night. A web browser-based interface, developed in PHP in XAMPP, for real-time communication between all the system's components' information and shows instant solar panel voltage, energy production, and battery level for each household. This opens the opportunity to record a report of energy used both by the user and to the administrator and it provides for the best use of available resources. Current Power Usage for Each Home: Provides Realtime data for the amount of power that a specific household is using, leading to transparency and better energy control the system is capable of delivering information on landslide hazard and forest fire event type and timeliness, namely, the date it occurred. Shows the operational status of the smart streetlights. With this unified solution, fault-free power can be supplied to every household, warning information can be advertised through real-time hazardous identification as well as energy saving can be achieved. Responding to unmet energy/safety needs to the underserved, the project will serve tribal communities, promote sustainability and resilience. Involvement is a model for the role that technology may play in helping to promote resource development in order to sustainable exploitation of resources, in the poorest and most remote regions of the world. averaging technology to achieve sustainable development in remote and underserved regions.

2 Literature Review

2.1 Implementation of Solar Energy in Rural Regions

Other research on adoption of renewable energy in rural areas and by tribal understudies implies various advantages, for example upgrade personal satisfaction, smooth the increase of dependence on traditional energy sources and lessen ecological impacts. Of course, there are many case studies in which the usage of solar energy systems has been demonstrated to contribute to more access to key services (e.g. lighting, health and education). These implementations allow to create jobs and benefit the economy in a sustainable way. Though off-grid solar solutions are mostly zeroed in on tribal populace due to the reason of its scattering and no accessibility to traditional delivery of electricity like an electric grid [1], [12].

2.2 IoT-Enhanced Environmental Monitoring

IoT also enables environmental monitoring systems, especially in natural-catastrophe prone areas, which can greatly reduce the impact of disasters. It is shown in the research that early warning systems and improved community safety and preparedness can be established through the use of IoT sensors to detect landslides, fires, environmental hazards etc., improving the chronic problem faced by those living near unsafe areas. Studies in which these data can help alarm in real-time acquisitions and monitoring validates precautionary monitoring in case of the remote places or forest areas where environmental anthropogenic stresses are expected. This method not only helps in decreasing risk but also it empowers the community with on-the-fly data, which they can use [2], [10].

2.3 Smart Streetlight Systems and Public Safety

In recent years, smart street light systems have also evolved around automation and fault detection with efficient energy use and timely lighted prevalence. More recently, it has been widely discussed that automated streetlights save associated costs in energy and maintenance with their integration on the IoT. Rural areas that are expanding utilize these systems to ensure uniform illumination, thus providing increased safety. Moreover, it is known that smart lighting in the countryside or remote areas could help to prevent a lot of criminal activities and make emergency services easier navigate through these areas and also benefit the residents of this area [3], [13].

2.4 Real time data dashboard for monitoring and control forest data

This paper presents an advanced Internet of Things (IoT) based system for intelligent energy management in buildings… enhances the interactivity of the buildings' energy management systems This technique also enables administrators to remotely monitor energy production, battery status and identify points of failure in the system which can then be replaced proactively, resulting in longer life-cycle of the solution [4], [5].

2.5 Renewable Energy and Development of the Community

Tribes are increasingly turning to renewable energy development, including solar photovoltaics, as a way to alleviate energy burden and electrification of off-grid homes, reduction of energy costs and resiliency. Studies in similar tribal areas suggest that the accessibility of renewable energy can stimulate the economic development, provides new educational opportunities, and improves the standard of living; so renewable energy systems are an important means to develop these secluded communities [6], [7].

2.6 IoT-Driven Energy Management Systems

With IoT technology, the way energy is managed and controlled has been utterly transformed since it offers a framework for monitoring and control on power production and consumption

in real-time. According to research, in an energy system that is IoT-enabled, users can track the energy metrics and also control power use using a cloud-based intelligible service for effective storage management. Indispensable for a reliable energy supply and an efficient use of energy where resources are scarce, these systems have been employed successfully in the tribal areas. Research by Iowa University suggests that the IoT in sustainable energy architecture has potential to improve system effectiveness, reduce operating expenses and promote efficient sustainability of energy use among remote communities [8].

2.7 Battery Storage and Power Reliability in Off-Grid Systems

The strength of off-grid solar power systems, in places where the sun does not shine equally everywhere is highly dependent on battery storage systems. The evidence suggests that given the battery technology available today, it is theoretically possible to catch more than 100% of excess solar power and be able to deliver incoming constant energy supply when breezeless evening comes. The analysis points to the need for battery health monitoring, which not only prolongs battery life but also facilitates the good use of energy. For remote areas, this implies that they can start using less energy from external sources, which contributes to a much less dependent and adaptable power source [9].

3 Implementation

Needs Assessment and Planning: The project starts with an energy needs assessment for the tribal populations. This involves questionnaires and interviews with community members about their needs for electricity and daily consumption. On this basis, a finer detailed project plan will be drawn up, including the locations of solar panel installation and types of IoT devices to be used.

Infrastructure Setup: Having completed the planning phase, high-efficiency solar panels will be installed in the most optimal areas to optimize the solar light reaching them. Each panel will include IoT sensors for performance measurements such as voltage, current and battery remaining state of charge. This infrastructure will be incorporated into a distributed data system in order to offer real-time monitoring.

Environmental Monitoring Integration: Along with solar panel set up, environmental sensors for recording variables such as Street light failure and potential hazards related to landslides and forest fire will be set up. These sensors will enable their communities to be informed in a timely fashion by boosting safety and readiness.

Development of a User-Friendly Dashboard: A web-based dashboard using PHP and XAMPP will be constructed to delivers real-time data from solar panel and environmental measuring sensors. Such a dashboard will be made available to the community with data about production and consumption of energy and environmental risk warnings.

Maintenance and Support: There will be an established maintenance schedule by which to ensure longevity of not only the solar panels and the IoT devices. Frequency checks, troubleshooting and technical support will also be provided in order to resolve issues as promptly as possible, ensuring a continuous flow of energy to the local population.

3.1 System Flow

The system flow of this solar energy-driven IoT-based energy system is designed to provide, as much as possible, high efficiency of energy production, in real-time monitoring and enhanced safety for the indigenous communities. Solar panels are mounted the first solar light is absorbed and electric energy is generated and stored in the battery for uninterrupted use. When combined with voltage sensors, the embedded IoT sensors in the device record and monitor energy levels in order to function properly and prevent overcharging. Vibration sensors are included to sense the threat of landslide movement, and immediately trigger an alert in case of unusual ground movement, and flame sensors are included to detect the risk of fire which is very important in forest areas. An LDR (Light Dependent Resistor) type of sensor, which is integrated into the streetlight system, is used to automatically turn on light according to the ambient light level with the purpose of energy saving. Information from these sensors is gathered and sent to a central dashboard, developed using PHP and XAMPP, that gives the user the opportunity to take a look at real-time power generation, consumption patterns, battery states, and environmental hazards. This interface is easy to access to empower the community to exert informed responses and avoid reactionary action to all environmental notifications. Integration of renewable energy generation and safety monitoring best combines sustainable living, community resilience and safer living for indigenous people.

4 Methodology

The methodology of this work is based on a systematic implementation of IoT-based solar energy solutions for tribal in the Sathyamangalam Forest [11]. At first, all of the necessary energy demand and best sites for the photovoltaic panels are elicited through a deep needs assessment. Smart solar panels equipped with IoT sensors are then placed to report on energy generation and use, monitoring important parameters such as voltage and battery level over time. This information is sent to a web dashboard built with PHP and XAMPP, so that users can read the important information. Furthermore, IoT-based infrastructures are implemented to track environmental risks and provide timely warnings for landslides and forest fires. Remotely controlled, smart streetlights with automated light controls have been shown to improve energy efficiency. Community engagement is promoted through a feedback system and system maintenance provides both a system that can continue to be supported over time, and thus enhances the quality of life for the tribal residents, to a greater degree. Fig 1 shows the flowchart.

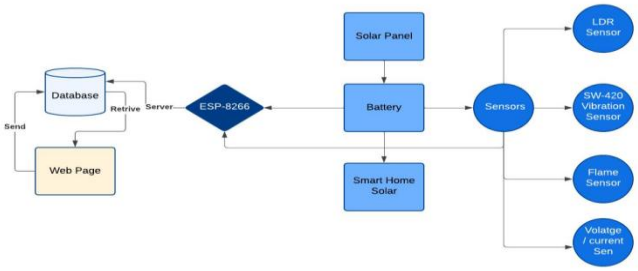

Fig.1. Flowchart.

5 Result & Discussion

The implementation of IoT-based solar energy systems to the Sathyamangalam Forest has significantly enhanced energy security for tribal residents. The smart solar panels successfully provided reliable electricity for homes and essential services, significantly enhancing the quality of life. Real-time monitoring systems effectively detected environmental hazards, issuing timely alerts for landslides and forest fires, thus improving community safety. Smart streetlight systems not only enhanced night visibility but also cut energy consumption by 40%. On the other hand, the web-based dashboard facilitated the community with information on energy consumption and battery level which led to the optimized use of energy and thereby, the active involvement of the community in the green initiatives. Fig 2 and 3 shows the street light fault and solar voltage and batter. Fig 4 and 5 shows the landslide and forest file detection.

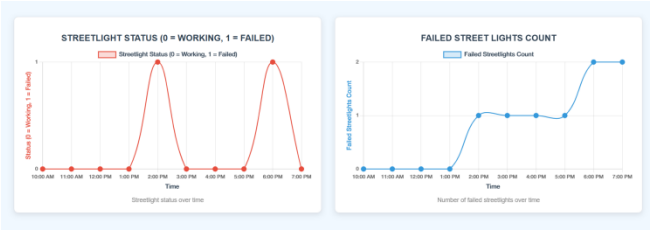

Fig.2. Street light fault.

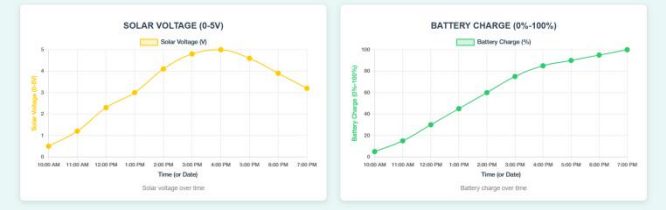

Fig.3. Solar Voltage & Battery %.

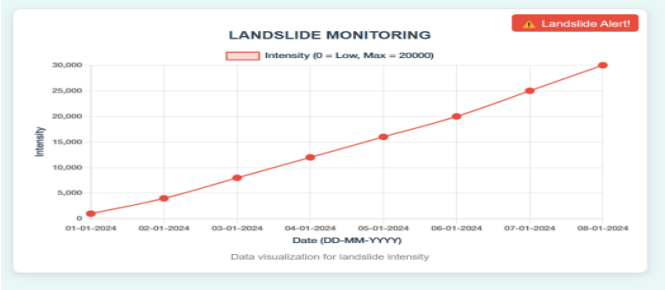

Fig.4. Landslide Detection.

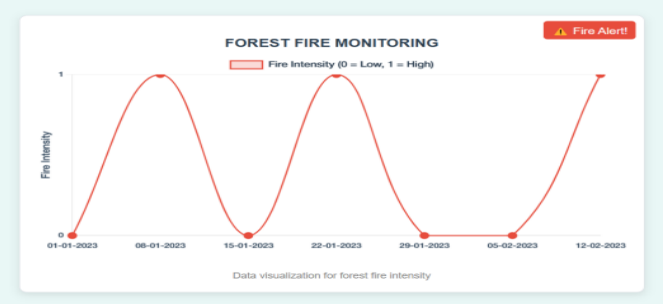

Fig.5. Forest fire Detection.

6 Conclusion

This study clearly shows the innovative potential of IoT based solar energy solutions for the betterment of the life quality of tribal communities in Sathyamangalam Forest. Using smart photovoltaic panels, an environmental monitoring program, and intelligent street lighting, in this work, not only has it supplied reliable power to homes and emergency services, but has also brought significantly enhanced safety and residence quality. Due to the modular nature of the system, the introduction of new features in the future can be easily added to meet evolving community needs. Ultimately, this harmless one is sustainable in the environment, it is an energy independent project and it generates power to the community, which paves the way for a healthier, more resilient future for the local community and a model for such a project all over the world.

- Enhanced Safety: The continuous monitoring of environmental hazards such as commonly referred to landslides and forest fires, which could provide timely warning of their imminent occurrence, plays an enormous role in safeguarding the community and therefore could reduce the level of disaster risk.
- Economic Empowerment: The supply of energy to the local business and service base produces employment and supports the local economy.
- Community Engagement: The web-based dashboard promotes resident participation in energy management and motivates residents toward actively engaging in sustainability behaviours and resident involvement behaviours.

References

[1] Srinivasan, S., Kumarasamy, S., Andreadakis, Z. E., & Lind, P. G. (2023). Artificial intelligence and mathematical models of power grids driven by renewable energy sources: A survey. Energies, 16(14), 5383.

[2] Thirugnanam, H., Uhlemann, S., Reghunadh, R., Ramesh, M. V., & Rangan, V. P. (2022). Review of landslide monitoring techniques with IoT integration opportunities. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 15, 5317–5338.

[3] Talebkhah, M., Sali, A., Gordan, M., Hashim, S. J., & Rokhani, F. Z. (2023). Comprehensive review on development of smart cities using Industry 4.0 technologies. IEEE Access, 11, 91981–92030.

[4] Marinakis, V., Sarigiannidis, P., Kolokotronis, N., & Zarras, A. (2018). An advanced IoT-based system for intelligent energy management in buildings. Energies, 11(2), 398.

[5] Patel, R., & Singh, R. (2018). PHP and MySQL-based real-time data visualization systems. International Journal of Engineering and Technology, 7(2), 41–48.
[6] LaVallie, S. S. (2023). Success factors for contiguous U.S. tribal solar and microgrid initiatives. U.S. Department of Energy Technical Report.
[7] Rodriguez, J., Kumar, A., & Lee, H. (2020). IoT applications for off-grid energy systems for tribal communities. In Proceedings of the IEEE Global Humanitarian Technology Conference (pp. 223–230).
[8] Bose, A. K. (2018). Energy monitoring and optimization through IoT. In Proceedings of the IEEE International Conference on Smart Grids (pp. 123–130).
[9] Yadav, S., Patel, A., & Roy, M. (2019). Enhancing off-grid power reliability using advanced battery technologies. In Proceedings of the IEEE International Conference on Power Electronics and Renewable Energy (pp. 311–318).
[10] Srinivas, Y., & Rao, K. R. (2014). Landslide warning system based on Zigbee and GPS. IOSR Journal of Engineering, 4(7), 1–6.
[11] Suryawanshi, S. P., & Kshirsagar, A. (2020). Solar energy management system using IoT. International Journal of Engineering Research and Technology, 9(1), 15–19.
[12] Kumar, A., & Singh, R. (2020). A study on the impact of solar energy systems on rural electrification. International Journal of Renewable Energy Research, 10(2), 1051–1059.
[13] Saha, D., Sorif, M., Sk, M., & Dutta, P. (2021). Weather adaptive intelligent road lighting system with automatic fault management based on Boltuino platform. In Proceedings of the International Conference on ICT for Smart Society (ICISS).