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Smart Renewable Microgrids for Rural India: An Iot-Based Hybrid Energy Monitoring and Control System

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Abstract

Rural and semi urban places in India are still faced with common power cuts, fluctuating voltages and inadequate exploitation of locally available renewable sources thus limiting socio economic development. In order to overcome these obstacles, this paper proposes Urja Pravah, an Internet-of-Things (IoT)-based hybrid microgrid monitoring and control system. The system combines solar and wind power with smart load and storage systems specific to the decentralized communities. The platform defines the real-time parameters of energy surpluses or deficits at the block level by recording generation, storage and consumption parameters through distributed sensors and embedded controllers and calculating these parameters in real-time. Based on this analysis, the non-critical loads are automatically switched on when excess energy is present and switched off when generation reduces, and the critical loads are insulated by priority-based supply. An energy-sharing scheme block level allows the export of excess energy blocks to provide the importing blocks and increase reliability and equity within the microgrid. An edge gateway gathers information and data provided by field controllers and sends it to a dashboard and mobile application, both hosted on the cloud, providing operators with live visualizations, fault or low-battery notifications, and manually overridden functions. The proposed system aims to reduce the number of outages, reduce reliance on fossil fuels, and assist the national goals of affordable and sustainable energy access in rural India through the incorporation of low-cost IoT hardware, open-source analytics, and renewable resources.

INTRODUCTION

Economical and dependable electricity is a key enabler to education, health, agriculture and small-scale industry in rural areas; however, there are still many Indian villages with frequent power outages and low quality of supply. Traditional centralized systems of distribution find it difficult to extend transmission infrastructure to sparsely populated regions with a high level of transmission loss and creating the need to rely on diesel-powered back-up systems [9] which add to the operational expenses and the emission of greenhouse gases. The promising option is the hybrid type of renewable microgrids that combine the local solar and wind power; however, their effectiveness depends on the accuracy of monitoring, complex load-controlling strategies, and the fair distribution of scarce energy sources to final consumers.

Recently, modern developments in the Internet of Things (IoT) and low-price sensors [11] as well as embedded controllers and cloud systems allow creating real-time monitoring systems even under the circumstances of limited resources. Nevertheless, a lot of the current deployments are centered on gathering data and its visualization but do not include automated logic to detect excess, prioritize loads, or predictive maintenance in response to the rural community requirements. Urja Pravah is designed to close this gap by providing an integrated hardware and software solution that automatically monitors solar and wind power generation, energy storage, and consumption. It then intelligently optimizes how energy flows across facilities, both at block and micro levels, ensuring efficient and reliable energy usage.

1. Related To Project

A. Hybrid renewable micro grids

Hybrid microgrids are multiple combinations of renewable sources (solar photovoltaics and small wind turbines) to reduce the intermittency and enhance the stability of the local supply. They can absorb short-term variations in production by incorporating energy storage (e.g. battery banks) and cover necessary loads at low-sunlight or low-wind times.

B. Hybrid renewable microgrids

Monitoring systems based on IoT make use of current transformers, voltage sensors, and energy metering modules in order to obtain real-time data regarding generation, storage status, and loads on consumers. This data is then relayed via microcontrollers and gateways to wireless networks like Wi-Fi, LoRa or cellular networks to centralized dashboards to be visualized and used to make decisions.

C. Predictive maintenance and operator support

Photovoltaic modules, wind turbines, energy storage units or communication nodes can fail in the field and significantly affect the performance of the system when they are not detected early enough. The suggested model will combine real-time sensing, anomaly detection, and mobile warning about the factors like reduced battery health or inverter issues to provide an operator with the interface built into the application to monitor the system, analyze its data graphically, and also control the load manually.

2. Hardware Components

The suggested prototype applies solar PVs and wind turbines as the main renewable energy sources that power into the microgrid. These sources are coupled with charge controllers, inverter and battery banks which process energy conversion to storage and delivery to loads.

Line currents, voltages, power and ambient conditions at different locations are measured by current transformers, voltage sensors[10], INA219 power sensors and environmental sensors at different points in the system. They implement simple decision-making algorithms to observe redundant energy and control loads. In this analysis, the nodes are used to remotely control the relay modules which are remotely operated to make or break the electrical loads. As a result, the system gets automatic control of both critical and non-critical loads in an effective and responsive way. An edge gateway is based on a Raspberry Pi, and it collects measurements on many controllers, does simple analytics and sends data to cloud services via communication technologies (MQTT, LoRa, Wi-Fi, 4G, or Modbus) and a mobile application and web dashboard implemented in frameworks such as Flutter or React provides the human-machine interface to operators.

3. Advantages

A. Enhanced Energy Access and Reliability

The hybrid solar-wind microgrid system, using the IoT, enhances the accessibility of power in micro-grids of rural and semi-urban communities that have limited grid facilities. This interdependence with a single source of energy is minimized by the integration of wind and solar energy. In case there is a reduction in the solar production because of the weather, the wind production can take its place and continuity of supply is achieved. This hybrid system reduces downtime and increases power availability in residential, educational, and medical premises, as well as in the small-scale industries.

B. Real-Time Monitoring and Smart Supervision

The system operates based on the IoT sensors to continuously monitor the parameters like voltage, current, energy generation, battery charge level, and consumption patterns. The information is sent to a central dashboard where operators could view live charts and obtain notifications. This enhances transparency and allows correction of irregularities to be taken immediately.

C. Intelligent Load Management

Surplus detection module measures real time energy available. At availability of excess power, it allocates the energy effectively over blocks. In case of shortages, non-critical loads are automatically switched off to conserve energy to use the services that are of high priority. This will help in ensuring maximum usage of energy and avoidance of overload situations.

D. Block-Level Energy Sharing

The microgrid separates distribution into blocks, which will enable equal exchange of energy among exporters and importers. In case one block produces a surplus energy and the other a deficit, then a redistribution that is controlled keeps the balance. This decentralization model empowers the microgrids and decreases the reliance on the external grids.

E. Predictive Maintenance and Fault Alerts

The system creates notifications about battery health deterioration, inverter problems, and wire problems. Early fault identification lowers the downtime and avoids unexpected system crashes. Predictive maintenance enhances the lifetime of the systems and enhances reliability.

F. Environmental and Economic Sustainability

The system enhances the use of renewable integration, which minimizes the reliance on fossil fuel and carbon emissions. An efficient use of energy results in saving of electricity which promotes environmental as well as economic sustainability.

Feature	Technical Benefit	Practical Impact
Hybrid Solar-Wind	Diversified generation	Reduced outages
IoT Monitoring	Real-time data visibility	Quick corrective actions
Intelligent Load Control	Automatic surplus detection	Efficient energy usage
Block-Level Sharing	Decentralized distribution	Fair energy allocation
Predictive Alerts	Early fault detection	Reduced downtime
Renewable Usage	Lower emissions	Cost savings

Table: Comparative Overview of System Features, Technical Benefits, and Practical Impact

4. Limitations

The model of the air guard safety helmet is designed FIND advancements like giving more accessibility to connect with the outer world more efficiently ,purification of the air that surrounds them while riding ,advanced features in judging the situations of accident prone area and give an alert to the nearest hospital to reach out for help .It also includes giving self-assessment alert to the rider based on their alcohol consumption. Despite this advancement in the model, it may include some drawbacks if not taken care of. It may include the following.

A. High Initial Installation Cost

Deployment must invest in renewable energy units, batteries, IoT hardware, controllers and the communication infrastructure. This preliminary capital need can be a hindrance in financially weak areas.

B. Dependence on Internet Connectivity

As the system is based on the real-time IoT communication and mobile monitoring, the lack of network connection in remote locations can interfere with the data transfer.

C. Renewable Energy Variability

The solar and wind generation is reliant on environmental factors. Sun rays and wind speed may vary leading to uneven power generation necessitating effective storage mechanisms.

D. Cybersecurity Risks

With data being transferred using communication networks and cloud systems, it has a potential vulnerability to cyber threats owing to the lack of appropriate encryption and authentication systems.

E. Grid Integration Challenges

It might be necessary to undertake technical changes and regulatory authorizations in order to integrate with existing grid infrastructure.

5. Limitations According The User

A. WEIGHT AND BULK

As the design of the model suggests the material of which the membrane is made of or the extra instrument added to the basics may increase the weight of the helmet causing an unease for the for the person during the time of the ride. It may increase the load at the rider's head and develop a pressure of handling it.

B. ACT AS DISTRACTION WHILE RIDE

Usually while riding we stop our vehicle to attend the call if it's important otherwise, we attend it later, but if we come in the use of such a helmet which reminds us about a call until we answer it. it will not be no less than a distraction. it will distract our mind and we will not be able concentrate on the road while riding vehicle. So, using it wisely is the need of user while e/she uses it.

C. SIDE EFFECTS OF SANITIZATION BY UV RAYS

The most recent researches on the reaction of uv rays on human 's skin us that how harmful they are to us. As for the removal of the bacteria from the helmet requires sanitization from uv rays, the left out uv particle on it may have a drastic impact on our skin .it may include dealing out with the skin irritation, redness and a certain amount of risk of getting skin cancer is also involved in it.

It may also damage the sensitivity of our skin.

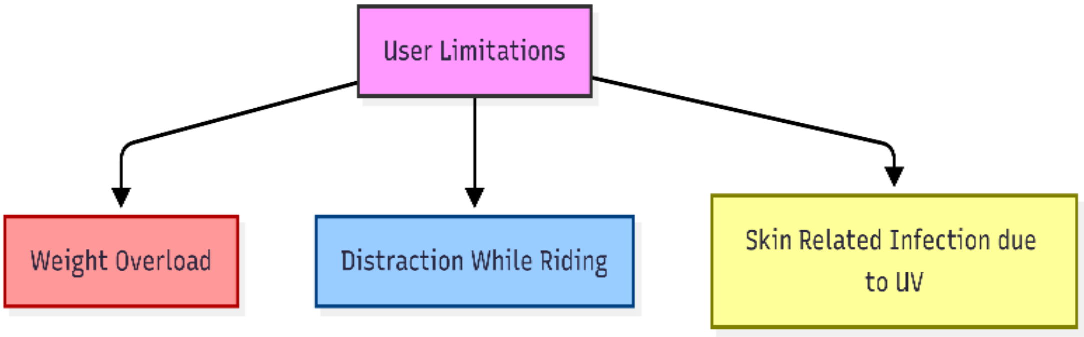

Figure 1. Factors Affecting Rider Comfort and Safety

6. Limitations For The Industry

A. COMFORTABLE MATERIAL

As discussed in the previous study in the report we can't use regular fabric material such as COTTON as it absorbs sweat and may develop fungal bacteria over it which may cause trouble later. If we use **foam** or **rubber** as the membrane of the model it may increase the skin irritation and lack the electrostatic charge over to distribute the strength over it.

B. COST EFFECTIVE FOR LOW GRADE PERSON

Any person who switches from one to another either finds flaws in their previous product or finds the new product in the market more useful. For a person who already uses a helmet that fulfills the basic essential

needs, **WHY WILL HE TRY A NEW HELMET**? is that what the question is. The answer to the possible **Firstly,** out of curiosity**Or a need to find solution for its problem For this a industrial need to be created for its use.**

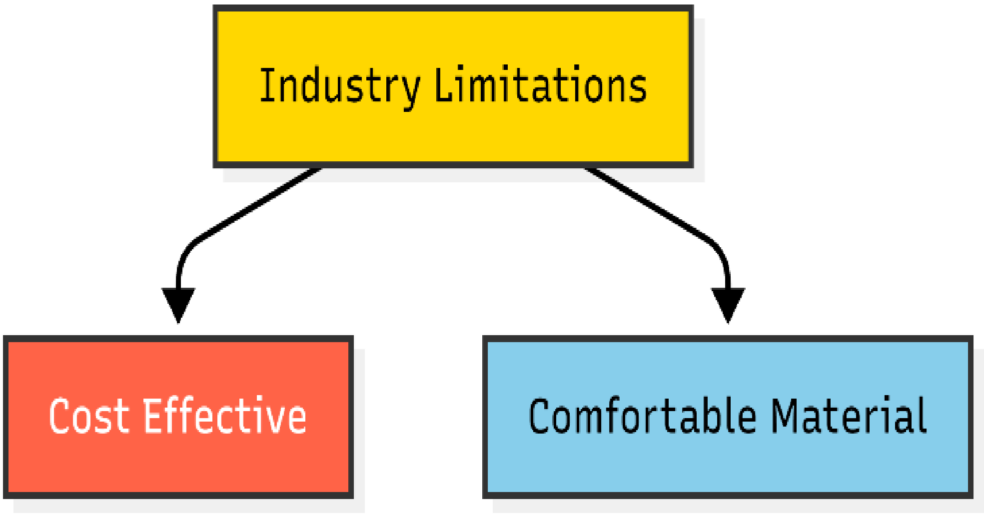

Figure 2. Industry-Level Design Constraints

7. Future Scope

The intelligence of Air Guard Helmet is futuristic thoughts to improve our surrounding by the means of health and avoid accident on roads. The principle of its working like tracking live location, health related alcohol monitoring, alerting the nearest hospital about the accidents, and purifying the air the user helps the rider in the terms of increasing its life expectany for the countries. The connectivity related advancement like Bluetooth, identifying the accidents and providing real time commination helps to connect the user to avoid unwanted disturbance during the time of ride. The model may also include many more futuristic thoughts to create the revolution the field of safety via helmets and facilitate the rides for its consumers.

8. Conclusion

Air Guard is a next generation safety helmet designed to promote head protection in association with the demand of fulfilling the futuristic technologies to enable the device monitor health and inhale a purified air. This includes a mask of multilayered stack N99-N95 to prevent the discomfort of the rider and provide the best the user. It also has some limitations for both the industry of production and the user. It is a double-edged sword. It works the best to create a healthy environment for the rider if used wisely. The limitations can be overcomed if taken care of concered matters.

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