Proceedings of Bhavisya Entrepreneur 2025: National Symposium on Entrepreneurship Innovation
ISBN: **978-93-343-9865-6**

NSEI/2025/05

Blockchain-Enabled Integration of Biogas and Solar Microgrids for Rural Resilience

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Abstract- In rural areas electrification face various challenges such as energy intermittency, inefficient management and lack of trust in decentralized systems. This paper proposes a blockchain based framework for integrating biogas and solar microgrids to enhance energy resilience in rural areas. This system leverages blockchain to address the challenges of energy poverty and grid instability by enabling a secure energy trading, transparent monitoring and decentralized Peer-to-Peer (P2P) energy trading network. Smart Contracts automatically manage energy trading, guarantee transparent and fair pricing, and verify the authenticity of renewable energy generation. By combining Biogas with Solar energy, this framework ensures energy availability and reduced carbon footprint in rural communities. Hence our analysis demonstrates that this approach reduces reliance on central authorities and fosters a local energy economy, thereby providing a robust and sustainable solution for rural electrification and development.
Keywords- Biogas, Blockchain, Microgrids, Peer-to-peer energy trading (P2P), Smart contracts, Solar energy.

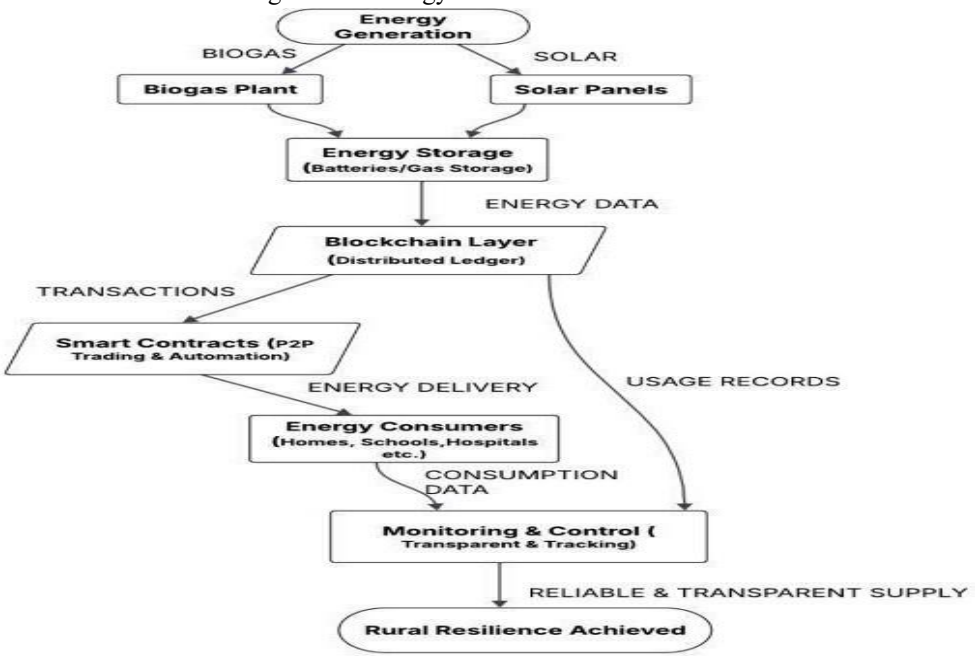
I. INTRODUCTION

Energy problems continue to afflict rural parts of the world, do you see? Diesel power is at the mercy of fluctuating fuel prices and the intermittent provision of diesel. Extreme weather due to climate change-heat, erratic rainfall, and more frequent storms-disrupts already fragile existing systems. In this scenario, off-grid renewables look like an attractive option. The hybrid microgrid system of solar panel and biogas setups is emerging. The solid foundation for waste management and disincentivizing the use of fossil fuels. Still, integrating and operating these dispersed energy sources pose challenges: balancing solar's variability with demand

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fluctuations, coordinating small-scale producers, and gaining trust among the stakeholders, which is often a contradiction against governance structures and create otherwise transaction costs. Blockchain is the

Fig.1. Methodology



real-time information on production and consumption with automated tracking of payments and the issuance of renewable energy certificates

The paper shows its contribution to the field in four main ways. First, it proposes an integrated framework of solar PV/biogas/battery with a lightweight, permissioned blockchain designed for rural peer-to-peer energy transactions. Second, it presents a model for assessing technical performance, economic assessment with scenarios assessing the trade-offs of cost, reliability, and emissions. Third, it presents the design and security-proofing of smart contracts for energy trading, subsidy management, and renewable certification in low-connectivity environments. Fourth, it presents a pilot study design, including metrics for system uptime, levelized cost of energy, user uptake rate, community satisfaction, and a discussion on policy and regulations that could enable scaling. Distributed ledger principles facilitated the selection of blockchain variants, consensus mechanisms, and data integration. Empirical case studies and testimonies from stakeholders ensure the practical relevance of the work with respect to technology and policy.

The goal stretches beyond proving simply its feasibility. It intends to give a full-fledged plan for applying to resilient rural electrification. The next section will review relevant literature and best case applications. Then, the proposed hybrid system with blockchain integration will be presented. The modeling approach and key findings will then be discussed. Finally, barriers to deployment, policy implications, and pathways

II. IDENTIFICATION-

[1] Great strides have been made since then. in the technology of generating and transmitting electricity. This

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comprise components like transformers, relays, switches, conductors, and many more that facilitate the safe delivery of electricity to end users. Historically, the power grid has had a centralized structure, in which electricity is produced at a facility and sent to several customers. The focal point being the facility.

[2] Real-time control, supervision, and monitoring systems with a smart protection system are necessary for enhancing the grid's reliability and overall efficiency. To maximize the generation and use of electricity. The main components of the conventional electrical grid system are electricity production, transmission, and distribution. Power plants produce electricity, which is then increased to high voltages for transmission. The majority of the electricity generated is transmitted at a very high voltage. the distribution networks via interconnected substations. Transmission is possible at either high voltage direct current (HVDC) or extremely high voltage alternating current (HVAC). The HVAC system is traditionally used, but the HVDC is becoming increasingly popular. especially over long distances, lower costs and losses led to greater popularity. It is also possible to transmit electricity using underground cables.
[3]. Erecting an underground transmission line system is typically 4 to 10 times more expensive than erecting an overhead line covering the same distance.

III. RESEARCH

According to this study, blockchain integration into the energy trading market has the potential to facilitate safe communication and payment methods. This integration is expected to result in a shift in the current smart grid architecture, moving away from a decentralized and centralized networking paradigm. The need for an updated energy trading system is well served by blockchain autonomy's inherent features of transparency, dependability, trustlessness, and trust. Several strategies that have been created demonstrate how blockchain technology may be used to revolutionize the energy sector and enhance energy trading.

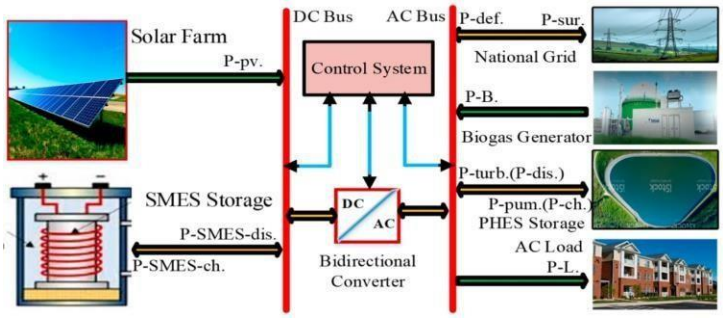


Fig.2. control system

IV. RESULTS AND DISCUSSION-

Environmental Sustainability- Switching diesel backups over to biogas might knock annual CO2 emissions down by 25 to 30 percent. That hinges on having steady feedstock sources, though. Blockchain also enables tokenizing carbon credits in a way you can verify. Rural folks get access to green funding through that. I

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mean, it's a strong play.

Resilience and Security- Distributed ledger tech wipes out single points of failure from centralized controls. Cryptographic hashing keeps metering data solid and intact. It slashes chances of fake reports big time. Oh, and it adds layers against tampering.

Scalability- With a solid blockchain build, the whole framework scales across more households without dragging on latency. Batching up transactions keeps the computing load and storage needs in check. So yeah, expanding it feels straightforward.

Limitations- Feedstock for biogas varies a lot, and that throws challenges into the mix. Rural communication lines aren't always steady. Operators around there need some training on managing energy with blockchain. Those are the key snags, anyway.

Reliability- Blending biogas production in with the up-and-down nature of solar PV, the hybrid approach should really dial back those supply hiccups. It ramps up energy access during grid blackouts. And blockchain takes care of the coordination, keeping household energy sharing clear and trackable. Basically, you can prove it all happened.

Economic Benefits- Smart contracts handle payouts automatically, cutting down on those transaction fees. They make local energy trades run smoother. Literature points out how blockchain microgrid setups slash operational costs, particularly in rural spots. Pretty direct stuff.

This setup shows real promise for rural energy needs. It strikes a good balance between dependability and eco-friendliness in practice.

Conclusion-This study shows a good future for renewable energy. The work pushes for things like building skills, good management, and using new tech, with the main thing being getting the community involved. This not only shows a way to strong, independent energy setups in rural India, but it also says getting the community into it is key for people to accept it and feel like they own it. Studies on local renewable energy plans in rural India have looked at good ways to fix the constant issue of not enough power.The study made clear that getting the community into it is very important, especially things like giving them power by adding tech, building skills, and good management.

By mixing blockchain's safe and hands-off nature with smart microgrids, the energy market can be cheaper and work better. . This lets people control their energy use more and trade energy, making the energy market more open and focused on the people using it.

Recommendations-

Governments, regulators, power companies, startups, and researchers should create

standards that let smart microgrids and blockchain solutions easily work together across different power systems.

Fund New Ideas: We need to keep researching and making the tech better. Let's put money into figuring out how to make blockchain systems bigger, safer, and more energy-saving. Also, let's back test projects to see

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if this stuff is really doable and worth it.

*Update the Rules:*The people who make the rules need to tweak them or come up with fresh ones to fit blockchain-powered smart microgrids and power markets. Clear rules will get people to invest, come up with cool stuff, and keep things fair, all while keeping our power supply safe and sound. If more people know what's going on, they'll be more likely to use it and join in on the new, spread- out power market.

Lock Down Security and

Privacy: Blockchain is usually secure, but we still have to watch out for weak spots and keep data safe. Putting in place stronger security and privacy steps will make users feel safer and protect their info in the spread- out energy world.These could get people excited about new energy trends and push us toward greener ways of doing things. So, blockchain, smart microgrids, and the power market have a lot of potential to change how we get power. This could lead to a greener, spread-out, and people-focused energy future.

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