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## MODERN APPROACHES TO ENERGY OPTIMIZATION IN IOT DEVICES USING HYBRID POWER SUPPLIES

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In today's Internet of Things (IoT) development paradigm, energy efficiency is of particular importance. A significant proportion of devices in this ecosystem operate under limited power supply, bringing autonomy, reliability, and sustainable energy provision to the forefront. Consequently, current research focuses on combining energy-efficient hardware with intelligent control systems and, above all, hybrid power supplies capable of adaptively responding to changing environmental conditions.

To provide a general overview of the system-level organization discussed throughout this review, fig. 1 illustrates a conceptual architecture of an IoT device powered by a hybrid energy supply. It reflects the interaction between energy harvesting units, storage systems, control algorithms, and communication modules that enable adaptive and intelligent energy management.

The diagram illustrates the integration of multiple energy harvesting sources, intelligent power management, adaptive local processing, sensing units, and bidirectional communication with edge and cloud infrastructure. AI modules support real-time decision-making and long-term prediction for proactive energy management.

A major advancement in this area is presented in [1], which proposes a hybrid energy system based on solar and wind power to extend the lifespan of IoT networks. The authors emphasize the need to transition from single-source systems to combinations capable of functioning in unstable environments. A key

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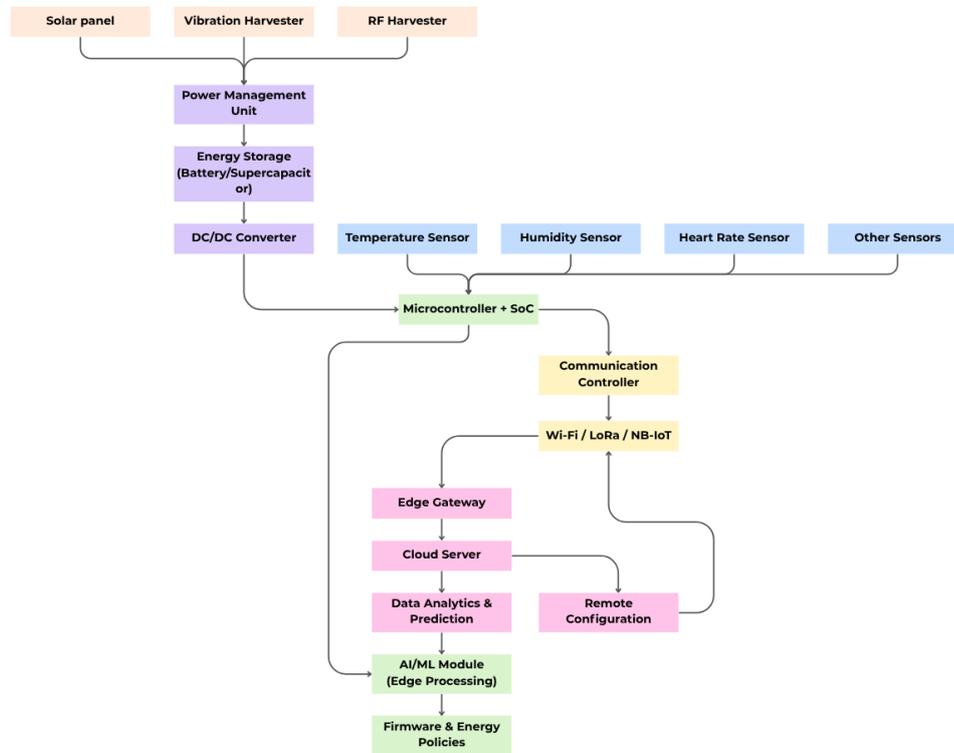


Fig. 1. Generalized architecture of a hybrid-powered IoT device

feature is energy-adaptive control, which dynamically adjusts the power source based on environmental and performance parameters, maintaining a balance between consumption and storage—especially relevant for devices deployed in remote or hard-to-access locations.

While [1] addresses engineering design, [2] marks a conceptual shift by integrating intelligent energy managers into photovoltaic systems. The authors argue that efficiency now hinges not solely on hardware but on forecasting generation and consumption amid fluctuating weather and behavioral patterns. They critique centralized architectures and advocate for decentralized models where IoT devices act as “data agents” in decision-making.

Building on this, [3] underscores the role of machine learning in forming resilient energy microsystems. Instead of static control, the study promotes dynamic load balancing via analysis of consumption, weather, and market data. Efficient use of renewables depends on accurate forecasting, with IoT technologies serving as the connective layer between infrastructure and analytics, enabling real-time feedback and system adaptation.

Expanding this further, [4] presents the Green-IoT system, which uses deep learning to shift from reactive to proactive energy management. Despite ongoing

refinement of simulation results, the core concept reflects enhanced autonomy—where devices not only respond to conditions but anticipate and adjust in advance.

Study [5] introduces economic feasibility and smart city-scale load strategies. Unlike prior research focused on generation, this study centers on consumption control during peak hours without compromising comfort. By integrating fractional PID regulation with dynamic pricing, the system encourages energy-efficient user behavior, making consumers active participants through feedback mechanisms.

In [6], energy supply is explored from the individual user's perspective. A compact, wearable IoT device for vital sign monitoring, powered by a hybrid harvesting system, shows that energy autonomy is achievable even in spatially constrained formats. This is enabled through flexible layout, efficient internal design, and microstructures that reduce electromagnetic interference.

Such hybrid solutions scale to consumer technologies, as shown in [7], which evaluates a solar geyser-plate system across efficiency, sustainability, and comfort. The novelty lies in merging energy management with multi-criteria decision analysis (MCDA), enabling optimization not by a single parameter but across environmental, economic, and usability factors.

Finally, [8] highlights the critical role of communication networks. Any IoT-based energy strategy is ineffective without stable data exchange. Hybrid AI models for anomaly detection in telecom systems enhance reliability and reduce power consumption of communication modules, making infrastructure support an integral part of energy-aware design.

In conclusion, modern strategies for optimizing IoT energy consumption are inherently multi-faceted—spanning autonomous device engineering to intelligent control at the urban scale. The shift from reactive to proactive management, and from centralized to adaptive hybrid systems, underpins the stability, scalability, and sustainability of global IoT energy infrastructures.

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