Powering the COLDEST City

A Smarter, Energy - Efficient, Affordable Grid for Yakutsk

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Yakutsk : A place colder than Mars

Yakutsk is the coldest inhabited city on Earth. But beyond the extreme cold, the biggest challenge is something invisible…

Energy inefficiency..

Figure 1. map of Yakutsk, Russia

Figure 2. Weather of Yakutsk

The Energy Crisis in Yakutsk

- Fossil Fuel Dependence → 2.97M tons of CO_2 annually.
- High Transmission Losses → AC power is inefficient.
- Unstable Power Grid → Voltage drops, blackouts.
- Permafrost Damage → Power lines are failing.

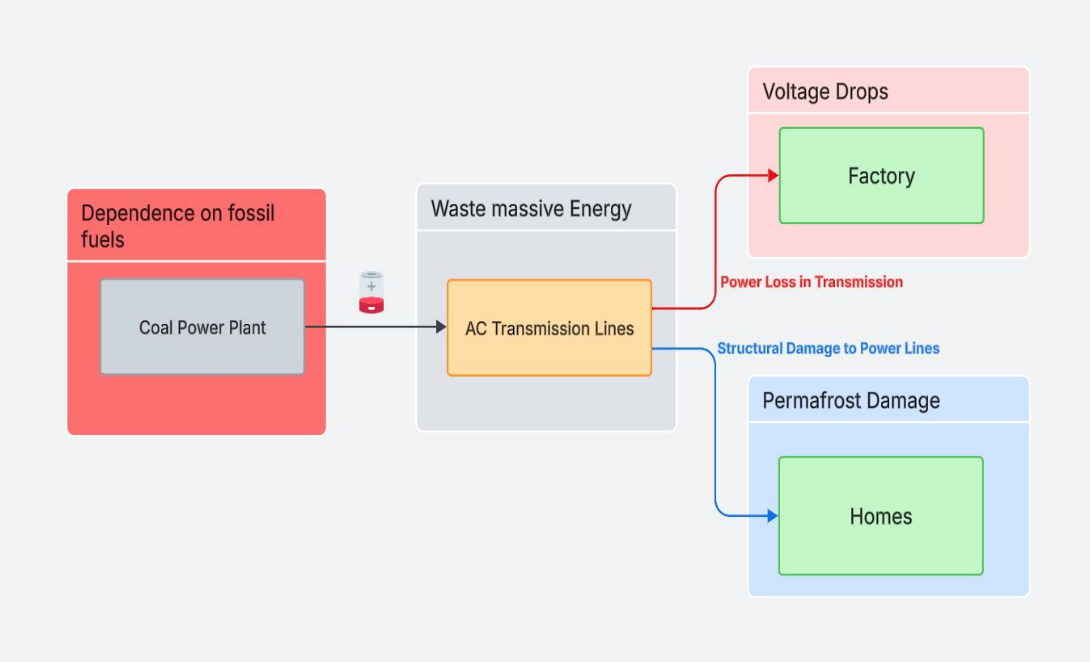


Figure 3. Block Diagram of Current Energy system in Yakutsk

Smarter , Stronger, Sustainable Grid for Yakutsk

- Reduce Energy Waste
  → Smart Monitoring prevents losses
- Stabilize the Grid
  → prevent blackouts
- Future-Proof Infrastructure
  → Built to survive extreme cold

Our Design : Smart-Grid Approach

I propose three key innovations...

1. HVDC Transmission
2. Smart Load Balancing
3. Real-Time Sensing

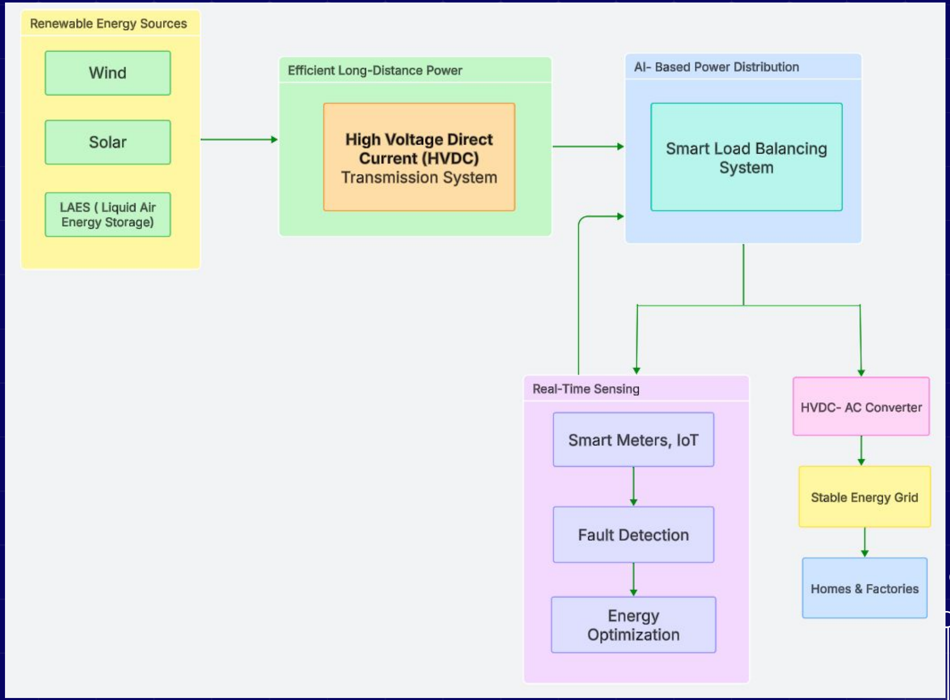
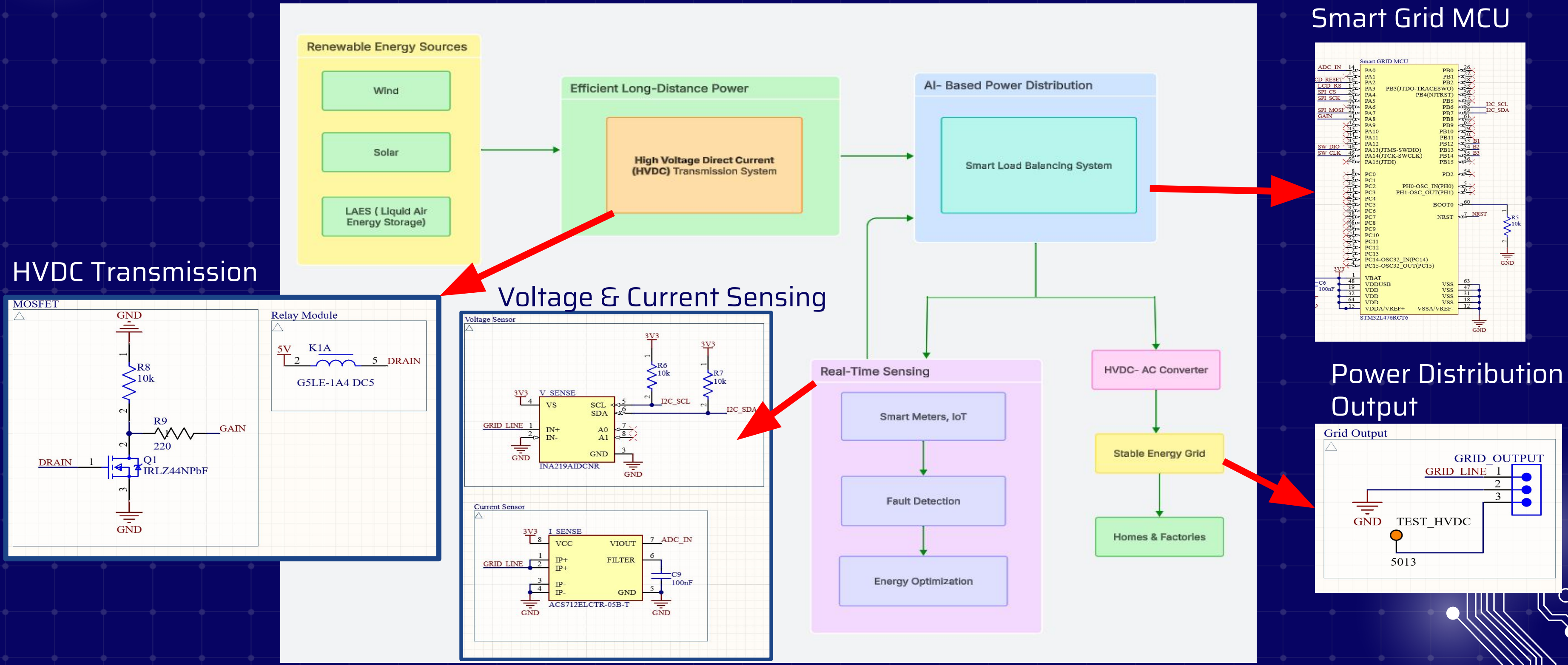


Figure 4. Block Diagram of Our Design using Smart-Grid Approach

Schematic Overview of Design

This schematic implements key features of the smart grid: efficient power transmission, real-time energy monitoring, and smart load balancing.



Smart-Grid PCB Design

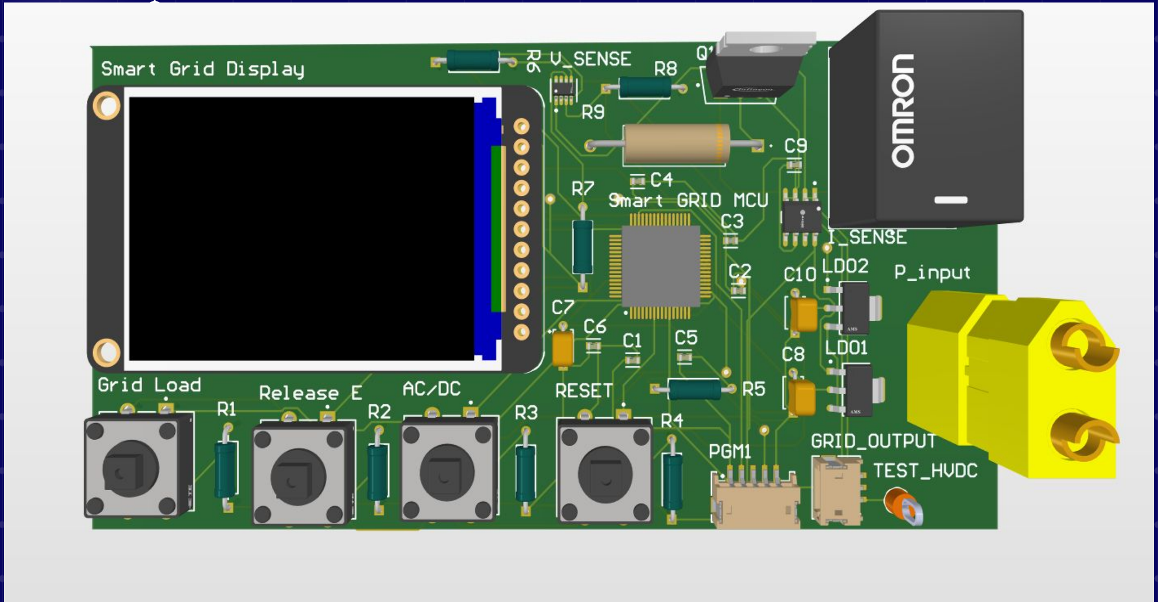


Figure 5. 3D View of PCB Layout for our smart-grid PCB

- One Compact smart PCB per neighborhood (efficient & scalable)
- Cold-Resistant User Interface (UI) Features
- Integrated Sensing and Load Management
- Designed for Extreme Cold Environments (-60°C Yakutsk)

→ Temperature Ratings for Components
→ Apply Conformal Coating
→ Use Polyimide (PI) or High-Tg FR4 PCB Material
→ transparent polycarbonate shield on display

Implementation Timeline

2025 -2030 — 2030 -2035 — 2035 -2040 — 2040-2050

2025 -2030: Research & Prototyping

- Smart Grid PCB Development
- HVDC & Smart Load Balancing Testing
- Arctic Simulation & Lab Testing

2030 -2035: Small - Scale Deployment

- Neighborhood Pilots in Yakutsk
- Real-world energy Monitoring
- Data collection for Optimization

2035 -2040: Expansion & Grid Integration

- Larger-Scale Implementation
- Renewable energy + AI Load balancing
- Government & Utility Partnerships

2040-2050: Full Smart - Grid Transition

- City - Wide Deployment
- Phasing Out Fossil Fuels
- Autonomous Grid with Real-Time Sensing

The Future of Energy in Yakutsk

- **Reliable & Resilient** – AI-driven grid prevents blackouts, ensuring stable energy supply.
- **Sustainable & Green** – HVDC + Renewables **cut emissions** and reduce fossil fuel dependence.
- **Affordable & Efficient** – **Minimizes wasted energy**, lowering costs for communities.
- **Scalable & Future-Proof** – If it **works in Yakutsk (the coldest inhabited region)**, it can work in **any Arctic region**.
- **Cold-Resistant & Durable** – Designed for **-60°C**, using specialized materials & coatings.

This solution paves the way for a sustainable, affordable, and reliable energy future in Arctic communities.

"If it works in Yakutsk, it can work anywhere."

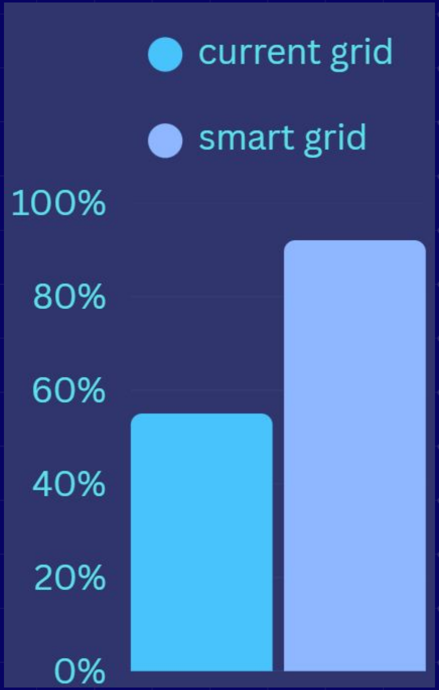


Figure 6. Bar graph comparison of energy efficiency

Thanks for Listening!

Additional Information including research and full schematic are provided in the Appendix.

Works Cited

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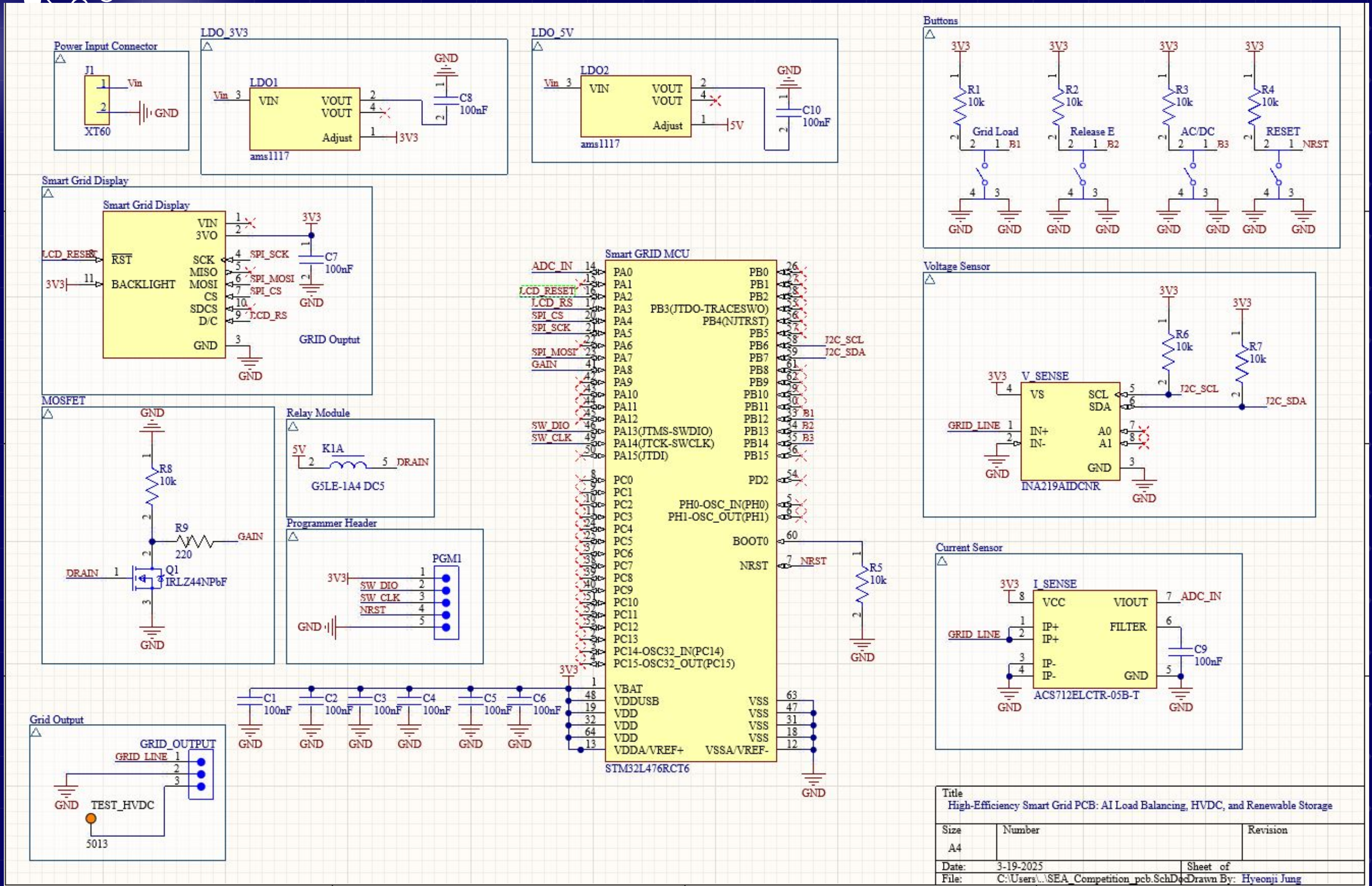
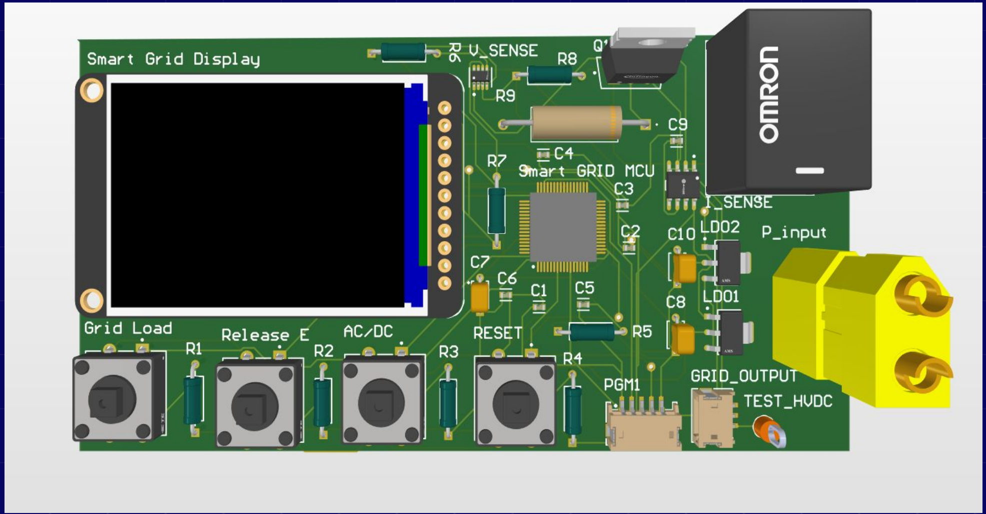
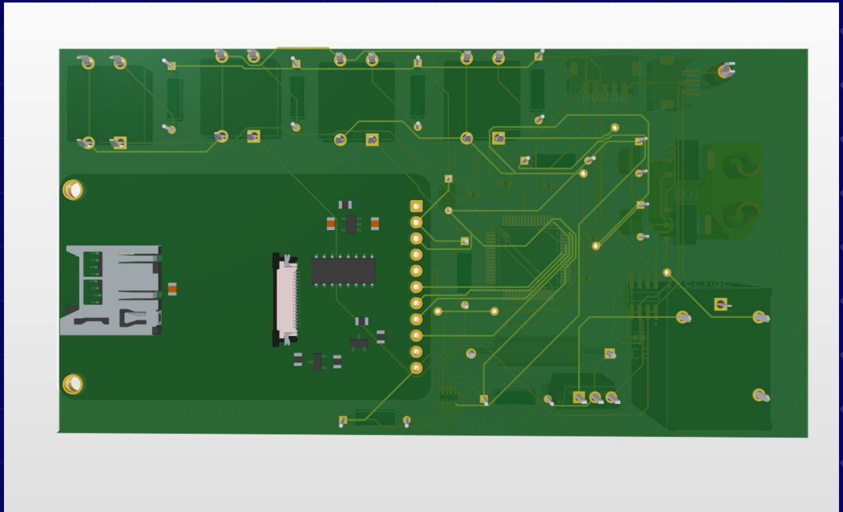
Appendix A. Full Schematic



Appendix B. 3D PCB Front & Back





Appendix C. LAES Research

1. LAES (Liquid Air Energy Storage)

- **What it is:** LAES uses liquid air as an energy storage medium.
- **How it works:** Electricity is used to liquefy air, which is stored and later expanded to drive turbines, generating power.

2. Why LAES is Suitable for Yakutsk

- Operates efficiently in **cold environments** (ideal for -60°C Yakutsk).
- Provides **long-duration energy storage**, helping balance intermittent renewable sources.
- **Scalable** solution that can store **grid-scale energy** for days.

3. Key Advantages of LAES

Zero emissions – Only releases air back into the atmosphere.
Long Storage Duration – Can store energy for **days to weeks**, unlike batteries.
High Efficiency with Waste Heat Recovery – Can integrate with industrial processes.
Works in Extreme Cold – No loss of performance in Arctic regions.

Appendix D. HVDC Research

1. What is HVDC (High Voltage Direct Current)?

- **HVDC is a power transmission technology** that efficiently delivers electricity over long distances with minimal losses.
- Unlike **AC transmission**, HVDC **reduces energy losses** and is ideal for remote areas.

2. Why HVDC is Essential for Yakutsk

Reduces Transmission Losses – Ideal for **long-distance energy transport** in vast Siberian landscapes.
More Reliable in Harsh Climates – Less affected by permafrost and extreme cold than AC grids.
Efficient for Renewable Energy – Supports **solar and wind energy integration** by reducing power fluctuations.
Scalable for Arctic Expansion – Can connect multiple Arctic communities with minimal infrastructure upgrades.

Appendix E. HVDC vs AC

Feature	HVDC	AC Grid
Transmission Losses	Low (~3% per 1000 km)	High (~8 -10% per 1000 km)
Efficiency	More efficient over long distances	Less efficient
Cost Over Long Distance	Lowe for 500+km transmission	Higher
Sustainability for Cold Regions	Excellent - Less power loss & fewer failures	Poor - AC line icing & losses
Integration With Renewables	Works well with intermittent sources	Unstable and needs synchronization