Dean&Francis
ISSN 2959-6157

Optimization and Application of DC Power Grids: Making Power Transmission More Efficient and Intelligent

Guiyi Kao

Jinqiu International School, Qingdao, Shandong, 266000, China
Email: kao0522@163.com

Abstract:
With the rapid popularization of clean energy sources such as solar and wind power, how to efficiently and stably transmit these energy sources has become a major challenge. Traditional alternating current (AC) power grids (such as the ordinary power grids at home) are gradually becoming inadequate in long-distance power transmission and control flexibility. At this time, DC power grids (which can be understood as power networks that transmit electricity using “direct current”) have become the “new favorite” for power system upgrades due to their advantages of low losses and flexible control. This article uses plain language to introduce you to the optimization technologies, practical applications, and future development directions of DC power grids, and see how it makes our electricity use more efficient and environmentally friendly.

Keywords: DC power grid, Optimization technology, Clean energy, Power transmission, Future development

1. Why Develop DC Power Grids?

1.1 “Pain Points” of AC Power Grids

The electricity we use in our daily lives is mostly alternating current. However, it encounters quite a few troubles during transmission:

· Large losses in long-distance power transmission: When alternating current is transmitted over long distances, a large amount of electric energy is wasted due to the “resistance” and “electromagnetic effects” of the lines. For example, when transmitting electricity from wind farms in the northwest to eastern cities, the loss in the middle may exceed 10%.

· Unstable integration of new energy sources: Solar and wind power generation is intermittent, and connecting them to traditional power grids can easily lead to voltage fluctuations and even power outages.

· Complex control: Multiple power plants and electricity consumption ends need to operate in strict synchronization, just like when dancing, everyone must step on the beat accurately, which is very difficult.

1.2 Advantages of DC Power Grids

If we compare the power grid to a courier network, the DC power grid is like an upgraded “high-speed rail line”:

· Lower losses: Direct current has no “electromagnetic losses” of alternating current, and can transmit 20% more electricity over the same distance.

ISSN 2959-6157

· Flexible control: It can freely adjust the transmission power and easily integrate the fluctuations of wind power and photovoltaic power.

· Plug-and-play: New power plants (such as wind farms newly built by the seaside) can be directly connected without the need for synchronization with the entire network.

Case: China's Zhangbei Flexible DC Project uses direct current to transmit wind power from Inner Mongolia to Beijing, reducing carbon dioxide emissions by about 15 million tons per year, equivalent to planting 800,000 trees!

2. Four Major Optimization Technologies of DC Power Grids

2.1 Structural Design: Making the Power Grid More "Robust"

· Multi-terminal interconnection: Traditional power grids are like "point-to-point couriers", while DC power grids are like "courier networks", supporting the simultaneous connection of multiple power plants and users. For example, Europe's "SuperGrid" connects the hydropower in Northern Europe and the solar energy in Southern Europe into a network, sending electricity to where it is needed.

· Modular converter: The core equipment "modular multi-level converter (MMC)" is like Lego blocks. Each module works independently, and the failure of one or two modules does not affect the overall operation.

2.2 Intelligent Control: Making the Power Grid More "Obedient"

· Adaptive regulation: Similar to the "intelligent power-saving mode" of mobile phones, the power grid can automatically adjust the transmission power according to the real-time load. For example, when the wind suddenly weakens, the system will instantly increase the output of other power sources to avoid power outages.

· Predictive control: Use algorithms to predict the power generation and electricity demand in the next few minutes, and optimize the line status in advance. Test data shows that this method can reduce losses by 15%.

2.3 Fault Protection: Making the Power Grid More "Safe"

· DC circuit breakers: Direct current has no "current zero point", and traditional circuit breakers have difficulty disconnecting fault currents. The new solid-state circuit breaker (similar to an ultra-fast switch) can cut off the current within 0.005 seconds, which is faster than blinking.

· AI fault diagnosis: Analyze the current waveform through artificial intelligence to quickly locate the fault point. For example, an experimental system uses deep learning technology with an accuracy rate of up to 99.7%, which is 10 times faster than manual troubleshooting.

2.4 Equipment Upgrades: Making the Power Grid More "Efficient"

· Silicon carbide devices: The new generation of power electronic devices (such as silicon carbide MOSFETs) can reduce the equipment volume by half and increase the efficiency by 5%. In the future, it may enable electric vehicle chargers to be fully charged within 10 minutes.

· Liquid cooling: Install a "mini air conditioner" on the equipment and use liquid circulation for cooling, which can extend the service life by 30%. For example, the DC power supply system of Shenzhen Metro has saved 15% of energy through this technology.

3. The "Applications" of DC Power Grids

3.1 Arteries of New Energy

· Ultra-high voltage DC projects: The ±800 kV DC project from Gansu to Zhejiang transmits 21.2 billion kWh of green electricity per year, equivalent to the power generation of 6.4 million tons of coal, directly supplying 20 million households.

· Offshore wind power integration: The UK's Dogger Bank offshore wind farm uses DC cables to transmit electricity to the land, with losses of less than 3%, while the traditional AC scheme may have losses of 8%.

3.2 Urban Power Upgrade

· DC microgrids: A community in Jiangsu piloted a "photovoltaic + energy storage" DC microgrid, using solar power during the day and battery energy storage at night, saving 18% on electricity bills.

· DC appliances: In the future, household appliances such as air conditioners and LED lights may directly use direct current, reducing conversion losses by another 10%.

3.3 High-reliability Power Supply for Industry

· Data centers: Alibaba's Zhangbei data center uses DC power supply, with a stability rate of 99.9999% (power outages of no more than 30 seconds per year), ensuring that online shopping festivals are not stuck.

· Metro power supply: Shenzhen Metro uses a DC traction system, which is not only quieter but also recovers the electrical energy during braking, saving 15% of energy.

4. Challenges and Future: How Can DC Power Grids Be Further Improved?

4.1 Current Challenges

· High cost: The price of silicon carbide devices is 3 - 5 times that of traditional silicon devices, just like 5G mobile phones were much more expensive than 4G when they first hit the market.For developing countries or economically underdeveloped regions, this poses a significant financial barrier, requiring coordinated support from government policies, capital markets, and the industrial supply chain.

· Lack of unified standards: The voltage levels of DC power grids in different countries vary, just like mobile phone charging ports have Type - C and Lightning, and unified rules are needed for interconnection.

· High Technical Thresholds: DC grids demand much stricter requirements for insulation, fault protection, and control accuracy. For example, DC circuit breakers must interrupt fault currents in a matter of milliseconds—a technical challenge still under active research. Furthermore, operations and maintenance staff need more specialized training, yet relevant educational systems and certifications are still underdeveloped.

4.2 Future Trends

· Smarter and More Digital: Future DC power grids will evolve beyond being mere "transmission networks" to become deeply intelligent system platforms. With the help of AI-based dispatch algorithms, real-time big data monitoring, and digital twin simulations, these grids will be able to predict power flows, optimize dispatching, and adapt to complex conditions with high resilience and efficiency.

· Digital twin: Build a "virtual replica" of the power grid to simulate scenarios such as typhoons and faults in real time and formulate emergency plans in advance.

· Integration with Hydrogen, Storage, and Blockchain: DC grids will increasingly merge with green hydrogen production and utilization systems—using surplus wind or solar power to generate hydrogen, which can be stored and later converted back into electricity using fuel cells. At the same time, blockchain technology may be used to trace each unit of green electricity, enabling transparent, verifiable green energy trading markets.

· Toward a Global Energy Internet: In the long term, DC power grids may serve as the backbone of a Global Energy Internet, connecting solar power from the Sahara, wind power from the North Sea, and hydropower from the Tibetan Plateau. This global interconnection would allow optimal cross-border energy sharing, helping to balance supply and demand on a planetary scale.

5. Conclusion: The Future of DC Power Grids Is Here

From photovoltaic power stations in the desert to electric vehicles in cities, DC power grids are quietly changing our way of using electricity.DC power grids are not just a technological innovation in electricity—they are a crucial pathway toward sustainable development. They are moving from "laboratories to remote deserts," and from "pilot projects to millions of households," becoming the backbone of a new energy system.

More importantly, DC power grids are driving a shift in how we understand and use energy: from centralized supply to distributed coordination, from passive consumption to proactive control, from generating power on demand to forecasting and optimizing in advance. They allow us to reimagine the role and potential of electricity—the foundation of modern civilization.

In the future, as DC power grids integrate deeply with artificial intelligence, clean energy, energy storage, and hydrogen technology, we may enter a new era where power is almost never interrupted, energy is intelligently managed, and carbon emissions are near zero.

By then, we may no longer care whether electricity is AC or DC—we will simply enjoy the freedom of using energy anytime, anywhere, and step quietly into a higher-quality future.

References

[1]Li, C. Y., Huang, H., Meng, X. Y., & Li, S. (2019). Analysis of the impact of MMC-HVDC system structure on multi-terminal DC grid faults. Title of the Journal in Italics, Volume(Issue), 49-12.

[2]Hao, H. Y., He, J. W., Sun, B. Y., & Wang, C. S. (2019). Coordinated power control of independent DC power grid based on series DFIG. Title of the Journal in Italics, Volume(Issue), pages.

[3]Liu, S. Q., Shen, B., Zhuang, J. W., Ke, Q. C., & Lei, R. (2019). Analysis and design of fast DC circuit breakers for in inverter power DC grids. Title of the Journal in Italics, Volume(Issue), pages.

[4]Zhu, S. C., Zhao, C. Y., & Xu, J. Z. (2019). Coordination of protection sequences for DC grids with various types of fault current limiters in action. Title of the Journal in Italics, Volume(Issue), pages.

[5]Mokhtare, M. H. (Year). Optimal sizing of a grid-connected DC microgrid for agricultural applications with water-energy management system considering battery cycle life. Title of the Journal in Italics, Volume(Issue), pages.

[6]Xiao, L. Y. (2013). Hybrid power grid model still needs another 30 years. Title of the Newspaper or Magazine in Italics, Date.