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Preliminary Analysis of Power Interconnection along the Belt and Road

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Abstract: As the Belt and Road initiative develops in depth and breadth, substantial achievements have been scored in multiple fields, such as infrastructure, trade and investment, and green finance. Power and energy are important areas for the Belt and Road international cooperation. To better understand the importance of international energy and power cooperation, this study elaborates the resource superiority of the Belt and Road countries for clean energy development from the aspects of environment and cost, and analyzes the potential of power connectivity among these countries. This study also analyzes the supporting role of technological revolution in power connectivity, in terms of thinking innovation, mode reform, technological innovation, and benefit sharing. Research shows that the energy and power demand of the Belt and Road countries is increasing rapidly, and the widely-distributed and advantageous clean energy resources of these countries have made power connectively possible. In the international energy and power cooperation, comparative advantages of all countries should be given full play, and key technology innovation in fields, such as renewable energy, power grid, and information, should be adopted to support the power connectivity.
Keywords: the Belt and Road; energy internet; clean energy; power connectivity; energy transition

1 International cooperation

Along with the continuous development and construction of the Belt and Road initiative, there have been fruitful achievements in the fields of interconnection, trade, investment, and green finance. In this context, energy and power cooperation are determining and have entered a new development stage.

In September and October 2013, Chinese President Xi Jinping delivered important speeches in Central and Southeast Asia entitled *Promoting Friendship between Our People and Work Together to Build a Bright Future* and *Jointly Building the China–ASEAN Community of Shared Destiny*, respectively. In those speech, the Silk Road Economic Belt and Maritime Silk Road initiatives were proposed for the first time, and they became the basis for the Belt and Road construction. For leading countries conducting international cooperation, some items are considered increasingly important, including open cooperation, harmony and inclusiveness, market-based operation, mutual benefits, policy coordination, facility connectivity, unimpeded trade, financial integration, and interpersonal bond among countries [1].

In terms of policy coordination, the identification of a common ground while reserving differences and strengthening friendly dialogue and consultation can guarantee regional development. By 2018, nearly 170

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countries and international organizations had signed the Belt and Road cooperation documents with China. In terms of facility connectivity, this initiative promotes interconnection of transportation, ports, energy, and communications. A number of landmark projects such as the China–Pakistan Economic Corridor, China–Laos Railway, China–Thailand Railway, Hungary–Serbia Railway, Jakarta–Bandung High Speed Railway, and China–Russia Cross-Border Bridge have steadily advanced. Moreover, trade barriers have been eliminated to achieve mutual benefits. By 2018, 933 enterprises have entered the international economic and trade cooperation zone, with a cumulative investment of 20.96 billion USD. In terms of financial integration, financing costs have been reduced, and the international competitiveness of regional economies have improved. Chinese banks have participated in more than 2 600 construction projects of the Belt and Road initiative, and the cumulative loans have exceeded 200 billion USD. In terms of interpersonal bonds, good neighborly friendship and cultural integration provide internal motivation for deeper cooperation. China has established education cooperation and exchange with 188 countries and regions.

Energy and power are the cornerstones of economic and social development, and they represent an important field of international cooperation in the Belt and Road initiative. In May 2017, the National Development and Reform Commission of China and the National Energy Administration of China jointly released the *Vision and Actions on Energy Cooperation in Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road*, which aimed to renew energy cooperation on the ancient Silk Road and promote energy cooperation between countries at a new level.

At present, the energy and power cooperation between the Belt and Road countries is in its early stages. Energy resources development, oil and gas pipeline interconnection, third-generation nuclear power stations, and ultra-high voltage (UHV) transmission technology have become new interests for international energy cooperation. The implementation of the China–Russia Yamal liquid natural gas project successfully created an important basis for the Ice Silk Road, which is the first extra-large energy project implemented under the Belt and Road initiative. The operation of oil and gas pipelines between China and Kazakhstan, China and Myanmar, and China and Russia effectively alleviate the pressure brought by the growing demand of oil and natural gas in China, and they generate a more diverse energy import and consumption channels. The Karachi nuclear power project in Pakistan is the second constructed Hua-long pressurized reactor (HPR1000) in the world after the Fujian Fuqing Unit 5. The Belo Monte ultra-high voltage direct current (UHVDC) transmission project in Brazil has achieved its first step to lead the export of UHV transmission technology, equipment, and experience.

Power interconnection is an important part of the facility connectivity on the Belt and Road initiative. It is also an excellent tool for international energy cooperation. In recent years, major power transmission projects from West to East and from North to South in China have significantly improved energy and power allocation capabilities. As countries pay more attention to the development of clean energy, the combination of comprehensive utilization of clean energy resources and efficient transmission of electricity has become an important direction of this energy transition. However, from the overall perspective of the Belt and Road initiative, the clean energy resources with significant advantages to be developed are unevenly distributed, and the level of power grid interconnection needs to be improved. To achieve a low-carbon sustainable development, it is necessary to systematically plan the clean energy development, further strengthen the power interconnection between countries, and strengthen the energy and power infrastructure.

2 Advantages of clean energy resources

Clean energy resources are abundant on the Belt and Road region. Through power interconnection, the comparative advantages of clean energy resources along the route can be optimally allocated within the larger scope.

2.1 Environmental advantages

The sustainability of clean energy is an important basis for its environmental advantage. A series of issues such as air pollution and climate change caused by the use of fossil energy have led governments, enterprises, investors, and the public to realize the need for a low-carbon global economy. Clean energy is more sustainable than the energy derived from fossil fuels, whose scarcity is becoming increasingly obvious. The use of clean energy reduces greenhouse gas emissions and promotes sustainable global development. It has been predicted that, if an energy system with 100% clean energy is realized by 2050, 24 million jobs would be created, 3.5 million deaths due to air pollution would be prevented, and 50 billion USD for treatments related to air pollution and climate

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change would be saved [2].

On the basis of clean development, the world has formulated feasible clean energy utilization policies and measures. In December 2015, the *Paris Agreement* was adopted to address global responses to climate change after 2020. For this purpose, each country developed a national development roadmap according to local characteristics, thus low-carbon and clean development of energy and power have become important responses for climate change. The Chinese government proposed that non-fossil energy will account for 15% and 20% of its primary energy by 2020 and 2030, respectively. The European Union and some developed countries, such as the United States, Japan, and the United Kingdom, have also considered renewable energy development an important measure to reduce greenhouse gas emissions. In the past two years, more than 60% of the power generation capacity installed in Europe and the United States derives from renewable energy. In 2015, the global installed capacity of clean energy exceeded that of conventional energy for the first time [3]. In addition, in September 2015, President Xi Jinping attended the United Nations Sustainable Development Summit and delivered an important speech, which proposed discussion on establishing Global Energy Interconnection to facilitate efforts to meet global power demand with clean and green alternatives. Under the Belt and Road initiative, the concept of Global Energy Interconnection has been consolidated and disseminated, thus providing new ideas for energy and power development and international cooperation.

2.2 Cost advantages

With the continuous technology advancement and scale expansion of industrial production, the cost advantage of clean power generation has gradually improved. In recent years, the cost of clean energy power generation dropped sharply. The levelized cost of electricity (LCOE) of photovoltaic (PV) and onshore wind power which were approximately 10 and 6 cents/kW·h in 2017, respectively, fell by 73% and 25% in 2010, respectively [4]. It is expected that the cost of clean energy production continues to gradually decrease compared to that of fossil energy, and thus the integration of clean energy production can be realized using the same feed-in tariff as that of thermal power generation.

The factors driving the decline in the cost of clean power generation mainly include technology, market, and financing. Continuous technology advancement is an important basis to reduce the cost of clean power generation. The continuous improvement of material, efficiency, and capacity leads to a continuous increase of capacity factor. Moreover, intensive clean energy development generates benefits and lower operation costs. In 2017, the average capacity factor of PV and onshore wind power reached 18% and 30%, respectively, and the average capacity factor of concentrating solar power (CSP) and offshore wind power reached 34% and 39%, which are closer to the hydropower average value at 48%. Continuous market improvement is also an important guarantee to reduce the cost of clean power generation. The auction mechanism has gradually replaced fixed electricity prices, and national subsidies for clean energy have been reduced. These policies greatly enhance the competitiveness of the clean energy market and promote the utilization of new technologies by developers to reduce the cost of clean power generation. In 2016, the number of countries using fixed feed-in tariff and auction mechanisms reached 83 and 73, respectively. Continuous financing convenience is an important supplement to reduce the cost of clean power generation. The financing of a clean energy market can be highly convenient. Lower loan interest rates and government bond income in European countries have led to a continuous reduction of its financing costs and continuous improvement of its competitiveness. The competitive auction mechanism has increasingly affected the expected rate of return on equity, which in the case of onshore wind power projects in Germany has dropped to 4.5%.

3 Power interconnection potential

The development potential and market space for infrastructure construction on the Belt and Road area are high. Energy and power represent an important part of infrastructure construction, and they are essential to ensure people's livelihood and promote development. The interconnection potential of countries is mainly reflected in the strong demand of energy and power, large price gap, and uneven distribution of energy resources and power load.

In 2016, the total population of 64 core countries (excluding China) of the Belt and Road area was approximately 3.2 billion people, which accounted for 44% of the world's population. The total gross domestic product of these countries was approximately 12.2 trillion USD, their primary energy consumption was approximately 5.7 billion tonnes of coal equivalent (tce), and their electricity consumption was approximately 5.3 $\times 10^{12}$ kW·h, and these values accounted for 16%, 29%, and 24% of the world's respective values. The average

annual growth rate of electricity consumption in China is 5.7% during the Twelfth Five-Year Plan period, and the electricity consumption reached 5.9 × 10^{12} kW·h in 2016, which was approximately 1.4 times that of 2005. Compared with 2005, the electricity consumption in the countries of the Belt and Road initiative increased by 61%, and this growth in key regions is shown in Fig. 1. Electricity consumption increased rapidly in Southeast Asia, South Asia, and West Asia–North Africa, whose average annual growth rates of electricity consumption from 2005 to 2016 were 5.7%, 6.7%, and 5%, respectively. The electricity consumption in the countries of the Belt and Road region are predicted to grow by an average annual rate of 3.2% in the next 25 years, which will be one of the fastest growing rates in the world [5].

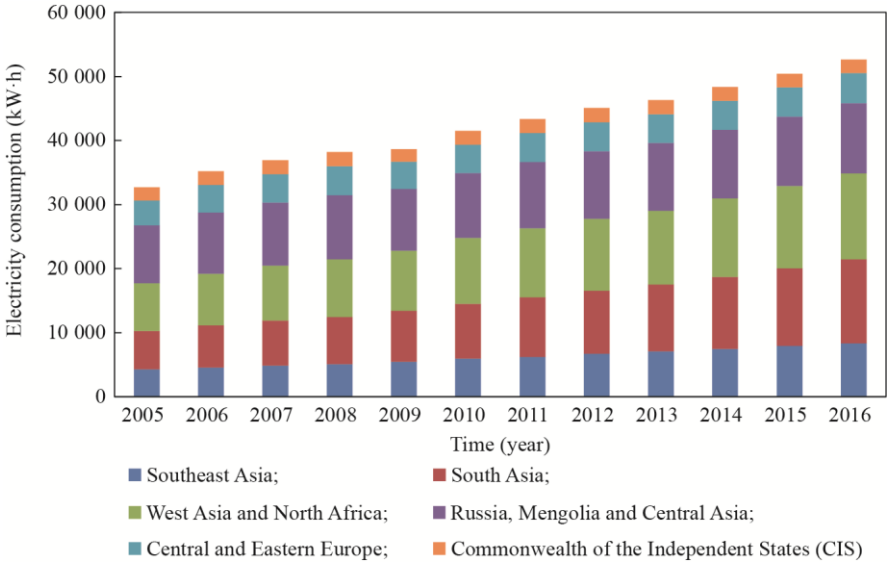

Fig. 1. Electricity consumption in the major Belt and Road regions.

The power demand of countries on the Belt and Road region has seasonal complementarity, and the differences in energy and electricity prices among them are high, which can provide certain potential for power interconnection. For example, due to the influence of latitude and climate, the peak loads in Russia and Mongolia mainly occur in the winter, while the peak loads in Japan, Republic of Korea, and the Democratic People's Republic of Korea occur in the summer. The average electricity price in the Republic of Korea and Japan are 2–3 times that of Russia and Mongolia [6].

The clean energy resources on the Belt and Road regions are mainly distributed in two energy belts. One is from West Asia and Central Asia to Northern China, Mongolia, and Russian Far East. The other is from northern South Asia, Southwest China, and Myanmar to Laos. The technical hydropower potential of 64 core countries of the Belt and Road initiative is approximately 4.9 × 10^{12} kW·h, accounting for 13% of the world's hydropower potential [7]. Russia and the Qinghai-Tibet Plateau concentrate the most hydropower resources. Wind power resources on the Belt and Road region are mainly distributed in China, Russia, Mongolia, Central Asia, West Asia, and South Asia; and solar power resources are mainly concentrated in China, Mongolia, Central Asia, South Asia, and West Asia. However, the population and power demand of countries on the Belt and Road area are mainly distributed in the coastal areas of East Asia, South Asia, and Southeast Asia, and these areas represent the opposite of the distribution of clean energy resources. In this context, electricity is a carrier for the efficient utilization of clean energy resources. Therefore, further strengthening power interconnection can provide greater and more effective regional advantages for mutual exchange and synergistic development of clean energy.

4 Support for power interconnection — technology revolution

Science and technology are important to promote energy transition and reshape the world energy pattern, thus being conducive to the development of clean energy and power interconnection.

4.1 Innovation thinking for energy and power development

Internet thinking is based on advanced information and communication technologies. It is an innovative

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thinking that can realize efficient interconnection and diversified utilization of energy and power. Internet thinking generates new economic forms. Traditional industries can be combined with Internet information technologies, and economic transformation and upgrading can be completed by optimizing production factors, updating business architectures, and restructuring business models. The combination of Internet and smart energy aims to promote the revolution of energy production and consumption, improve the proportion and utilization efficiency of renewable energy, optimize energy structure, save energy, reduce emissions, and accelerate the intelligent transformation and interconnection of power infrastructures.

Power interconnection is an important supplement to the traditional energy production, transportation, and consumption. It is also a new form of low-carbon development, which provides more choices for energy supply and consumption. Advanced information and communication technologies such as big data, cloud computing, Internet of Things, mobile Internet, and artificial intelligence can be used to promote a diversified, low-carbon, clean, and comprehensive energy development. They can also be used to improve energy efficiency, reduce costs, and better meet the demand of users for various types of energy. The development of these information and communication technologies will promote the revolution of the entire process of power production, transmission, and distribution. In power production, the application of big data and cloud analysis significantly improves the utilization rate of renewable energy. In power transmission, advanced sensing technologies can provide quicker and wider security for the power grid. In power distribution and utilization, intelligent technologies such as the Internet of Things and mobile Internet improve the diversity of terminal services, which can meet different requirements, drive new ecosystems and value-added services, and improve the operation efficiency of energy systems.

4.2 Revolution of clean energy technology and industrial models

The consumption of clean energy is increasing throughout the globe. In 2015, clean energy on the Belt and Road region accounted for approximately 27% of the total energy installed capacity. While clean energy utilization levels continue to increase, clean energy technologies have undergone tremendous changes. The performance of PV modules and wind power equipment have been steadily improving, and offshore wind turbines with 12 MW capacity are being developed. The forecast levels of renewable energy production have been continuously optimized. Based on real-time observation data, the prediction accuracy of short-term power generation by wind and PV in China reached 92% and 91%, respectively. In this context, friendly integration of renewable energy can be realized. In the Zhangbei national demonstration project, wind power, solar power, energy storage, and intelligent power transmission are integrated to automatically configure seven kinds of power generation modes, such as the combination of wind and energy storage. In this project, the renewable energy utilization efficiency reaches 98%.

With the continuous progress of clean energy technologies, it is possible to further improve the proportion of clean energy on the supply side and the level of electrification on the consumption side. At the same time, new choices and paths are formed for most countries to develop a low-carbon and sustainable energy system. Their industrial energy supply and consumption dynamics should be transformed into a circular industrial chain, where an efficient closed-loop feedback system includes energy development, consumption, and industrial production. There are precedents in the field of energy and mineral development in China, and a circular industrial chain such as “coal – coal washing – power generation – aluminum oxide – building materials” has been formed in Ordos, and it has produced economic and environmental benefits. The energy and mineral resources of countries on the Belt and Road have their own characteristics. These diverse characteristics provide comparative advantages in a wider range, form a more extensive circular industry mode, integrate the development of multiple industries, and lead several fields to enter the international market. Due to the resource endowments of countries on the Belt and Road, clean energy can be vigorously developed, and energy and power interconnection can be strengthened. These achievements can ensure adequate and reliable energy and power supply; promote the development of green and low-carbon industries; form an integrated layout of energy, mining, metallurgy, and deep processing; and co-develop electricity, mining, metallurgy, manufacturing, and trade. The development of clean energy technologies and the revolution of industrial models are the catalysts to promote the interconnection of electric power infrastructures.

4.3 Strong and smart grid with innovative power technology as the core

Strong and smart power grids are modern systems highly integrated with flows of power, information, and

businesses. Their basis is a strong grid structure. A communication information platform and intelligent control are used as support of smart grid. Innovative technologies such as UHV, flexible transmission, energy storage, submarine cable, intelligent control, and information communication are important foundations to build a strong and smart power grid.

By 2018, China had constructed 21 UHV transmission projects, including 8 ultra-high voltage alternating current (UHVAC) projects and 13 UHVDC projects. At the same time, UHV technology has also been adopted in Brazil and India. The first phase of Belo Monte UHVDC transmission project in Brazil started operations in 2017, and three UHV projects are in operation or under construction in India. In the field of UHV engineering science and technology, China has realized innovation and application throughout the following steps: fundamental research, project design, equipment manufacture, test verification, system integration, and project demonstration. There have been breakthroughs for the core technologies of UHV transmission, and 18 international standards and 137 national standards have been developed, thus leading to the development of the UHV technology worldwide. In recent years, power electronic technologies have presented great progress, and they have been widely used in the fields of transportation, aerospace, energy, and power. Flexible power transmission has become an important measure of renewable energy integration. The Nanao ±160 kV 3-end, Zhoushan ±200 kV 5-end, and Xiamen ±320 kV VSC-DC projects have been built, and they enhance the capability of power supply to islands and the consumption of renewable energy. The application field of flexible transmission has been expanding in the past decade. Zhangbei ±500 kV 4-end VSC-DC power grid demonstration project is under construction to support the 2022 low-carbon and green winter Olympics. This project integrates wind power, solar power, energy storage, and pumping storage. A strong and smart power grid is a product of advanced power technologies, and it is an important measure to realize power interconnection and build a new mode of global energy and power governance.

4.4 Comprehensive energy utilization based on multilateral participation and benefit sharing

Economic globalization and regional integration have accelerated energy marketization. In a fair and open market environment, multilateral participation and benefit sharing are the basic principles for market operation. The comprehensive utilization of energy cannot be separated from an open market, and there are challenges for the integrated development of energy fields.

A comprehensive utilization of energy is realized by an integrated energy system, which is formed by the coordination and optimization of various energy production, transmission, distribution, and consumption systems [8]. An integrated energy system involves energy networks at terminal, regional, national, and even intercontinental and global levels. Smart grids are the core of comprehensive energy utilization. Multi-energy complementarity can be achieved through smart grid construction, which can improve the efficiency of energy utilization and achieve a low-carbon sustainable development. When exploring and utilizing the complementarity and substitutability of various energy sources, their advantages should be considered to optimize the process from power sources to power load. New energy international cooperation modes with multilateral participation and benefit sharing should be built, and research on the comprehensive utilization of energy technologies should be actively conducted. Thus, a comprehensive utilization of energy can be accomplished in a wider range and on a broader platform, and energy and power interconnection can be performed.

5 Conclusion

This paper describes the advantages of clean energy resources and potential of power interconnection on the Belt and Road region. The supporting role of the technology revolution on power interconnection was explored from the aspects of innovation, clean energy technology, industrial model revolution, UHV, smart grids, and comprehensive energy utilization. It was suggested that innovation and cooperation in the field of energy and power technology should be conducted based on basic research, technical breakthrough, and engineering demonstration. It is important to lead the energy transition of the world and feedback to the domestic market and, at the same time, to realize the export of energy and powering of industrial chains.

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