Doctoral Dissertation Doctoral Program in Electrical, Electronics and Communication Engineering (33thcycle)

Economic and financial analysis of EU Power Grid under Global Energy Interconnection

Duo Li

supervisors
prof. Ettore Bompard
prof. Francesco Profumo

Politecnico di Torino
2021

Abstract

Facing the continuous expansion of energy demand and the continuous deterioration of environmental problems, the Global Energy Interconnection, as an emerging smart energy ecosystem and an important way to configure and solve human energy supply and environmental problems, has been widely concerned by various countries to establish a safer, more efficient, environmentally friendly, economical and sustainable energy utilization model, and optimizes energy from a global perspective. The vision of the Global Energy Interconnection is to strengthen the deployment of renewable energy power generation on a global scale through the construction of intercontinental transmission corridors, thereby promoting global decarbonization. Global Energy Interconnection with UHV grid as the backbone is a global energy allocation platform with a wide range of services and strong reliability, and its economy is helpful to realize the comprehensive and coordinated development of transnational transmission lines. The basic structure of the Energy Interconnection is based on the power system with renewable energy access as the core, supported by advanced information technology and power electronic technology, and the coupling of multiple energy networks (cold, heat, gas, and electricity) to realize the integration of complementary advantages and coordinated operation of multiple energy sources.

In the context of the Global Energy Interconnection, this thesis conducts economic and financial research and analysis on European power grids.

Firstly, the European power grid is the world's largest regionally interconnected power grid, the world's largest power grid with the largest total installed capacity of power sources, and it is also the world's rare power grid that has achieved interconnected operations in multiple countries. Based on the analysis of fossil energy consumption and CO2 emissions in European countries, this thesis analyzes the impact of European power grids on global warming and summarizes the necessity to promote energy transition and a high proportion of renewable energy consumption. In addition, the energy imbalance of the European power grid is analyzed, including the imbalance of European power supply and demand, the imbalance of users, and the imbalance of geopolitics. The construction of the Global Energy Interconnection has certain guiding value for the construction of European power grids. Therefore, based on the analysis of the energy status of European countries, this thesis summarizes the global energy interconnection from the aspects of renewable energy development, large-scale interconnection, and smart grid construction, and analyzes the advantages and disadvantages of the construction of the global energy Interconnection.

Secondly, the challenge of worldwide energy decarbonization is crucial to assure a sustainable development. The achievement of decarbonization encompasses not only a considerable exploitation of renewable energy sources but also a paradigm shift in final energy uses towards their massive electrification. The electrification based on global energy interconnections (GEI) is one of the possible pathways towards decarbonization in energy systems. In this thesis we critically discuss the idea of decarbonization through global interconnections in an "electricity based" world, contrasting it against the typically desirable attributes for energy in terms of security, efficiency, sustainability and affordability. We provide a comparative analysis of global interconnection with other internationally proposed visions of future energy scenarios. The analysis shows that the GEI option could be particularly beneficial; however, it requests deep and relevant modifications in the energy markets and regulations in which a common framework based on the cooperation among different countries is needed.

Thirdly, to carry out a thorough investigation on the global energy interconnection, the entire world was accounted, dividing it in 15 geographical world regions, chosen to build a homogeneous regionalization scheme, either geographically or culturally, as well as the economic background and increasing trends. Per each world region, a general, energy and electricity characterization was performed. In particular, general figures comprehended basic information on surface, population, Gross Domestic Product (GDP) and access to electricity. The energy characterization was undertaken with respects to primary and secondary commodities, focusing on energy production, imports, exports, total primary energy supply (TPES) and total final consumption (TFC) data. Finally, an electricity characterization of the selected world regions was performed, in terms of installed capacity, annual electricity generation, load curves and winter peaks. Furthermore, the network model that is used for the development of the accommodation infrastructure for the EU is discussed, with a special focus on the extension of the network into the year 2030 and 2050.

Further, the thesis analyzes the economics of the global energy interconnection. Under the macro background of the global trading market, according to the constructed global energy interconnection scenario, the regional optimal power generation is analyzed based on the regional optimal dispatching power generation capacity provided by the best optimized power flow simulation, and the LCOE is used as a research indicator to collect power generation cost data to optimize Power flow, dispatching power at the lowest cost; in addition, this thesis analyzes the unit cost from multiple power infrastructure index sets and corresponding reference values, constructs the cost calculation model of the intercontinental transmission line, and summarizes the different applicable intercontinental grid scheme. At the same time, by using economic benefits as indicators, the economic benefits brought by the global energy interconnection architecture structure to European countries are analyzed, and the

impact of different transmission schemes on investment costs and various electricity prices is calculated.

In addition, in view of the many risks that may be faced by transnational energy Interconnection investment, this thesis identifies 27 risk points from the three levels of countries, enterprises, and projects; establishes a optimization model by structural entropy-factor analysis method to select key indicators for transnational energy Interconnection investment risk evaluation, collects the opinions of 30 experts in related fields on the importance of 27 risks through electronic survey questionnaires, and analyzes the survey data to obtain typical 17 key indicators that can comprehensively reflect risk characteristics. Finally, taking the transnational power grid project as an example, this thesis establishes a TOPSIS cross-border power grid investment risk evaluation model based on the combination of AHP and righteousness method, and selects three transnational transmission projects in the planning database of a country as the evaluation objects to verify rationality of the index system and evaluation system.

Finally, the Energy Interconnection is a user-centric smart system that enables users to flexibly use various energy sources through the real-time interaction of devices in different systems. Therefore, people are an important part of the interconnection, and human behaviour and human-to-human interaction have an important impact on the operation, planning, supervision of the system and the market. Based on this, this thesis starts from the social attributes of the Energy Interconnection and focuses on the interaction between people and the multi-energy flow system, and proposes the Social Energy Internet. First, the importance and connotation of the social energy Internet are explained from the perspective of the interaction between people and systems, multi-disciplinary integration and multi-dimensional integration. Secondly, it discusses the physical characteristics and research framework of the multi-energy flow (energy flow, traffic flow, social flow, and information flow) coupling system considering social networks, and describes the planning and operation model and coordination operating mode of the social energy Internet considering human behaviour. Finally, the research direction of the Social Energy Internet is prospected.

Keywords: Global Energy Interconnection; European Power Grid; Economic Analysis; Investment Risk; Social Energy Interne