

A Vision of China-Arab Interconnection Transmission Network Planning with UHVDC Technology

Wu Dan¹, Liu Yujun¹, Yin Hongyuan¹, Xu Qingshan¹, Xu Xiaohui² and Ding Maosheng³

¹School of Electrical Engineering, Southeast University, Nanjing 210096, China

²China Electric Power Research Institute, Nanjing 210003, China

³Ningxia Electric Power Company, Yinchuan 750001, China

liuyujun@seu.edu.cn

Abstract. Developments in ultra-high-voltage (UHV) power systems and clean energy technologies are paving the way towards unprecedented energy market globalization. In accordance with the international community's enthusiasm for building up the Global Energy Internet, this paper focuses on the feasibility of transmitting large-size electricity from northwest China to Arab world through a long-distance transnational power interconnection. The complete investigations on the grids of both the sending-end and receiving-end is firstly presented. Then system configuration of the transmission scheme and corridor route planning is proposed with UHVDC technology. Based on transmission costs' investigation about similar transmission projects worldwide, the costs of the proposed transmission scheme are estimated through adjustment factors which represent differences in latitude, topography and economy. The proposed China-Arab transmission line sheds light on the prospects of power cooperation and resource sharing between China and Arab states, and appeals for more emphasis on green energy concentrated power interconnections from a global perspective.

1. Introduction

Clean energy and electric energy substitutions are directing the way of energy revolution and judging by the highly uneven distribution of renewable energy around the world, a networking coverage of power grids for worldwide use of bulk transmission is expected [1].

Special attentions have been paid to a HV/UHV grids backbone to support large-scale, cross-border optimization and allocation of clean energy globally. In recent years, China's UHV transmission technology has developed rapidly which is responsible for transmitting power from northwest and southwest to load centers - eastern coastal areas. The transmission distance has advanced from hundreds of kilometers to thousands of kilometers and single-line transmission capacity up to 8GW [2].

High-voltage direct current (HVDC) has been used in power transmission systems for over 50 years; its main applications are the interconnection of nonsynchronous AC networks, long-distance electricity transport, and submarine and underground cable transmission [3]. It is verified that above certain economic distance, the advantages of HVDC would make it the preferred option over AC transmission in the context of point-to-point transmission without intermediate taps, as well as higher cost efficiency and lower power losses [4]. Ultra high-voltage direct current (UHVDC) systems operating at 800kV or above, in particular, are economically attractive for power transmission rated at 5-12 GW [5,6].



In this paper, a general overview of energy resources and power grids in northwest China and Arab Gulf states is depicted including their generation, transmission network, and electricity demand. Accordingly, based on HVDC theory, a new cross border transmission line between China and Arab states is framed in order to meet the increasingly intense electricity demand of Gulf Cooperation Council (GCC) region. The early-stage cost estimation of the proposed transmission scheme are carried out for further feasibility analysis. Also, the next course of action is clearly outlined which will concentrate on in-depth financial evaluation of alternative plans.

2. Energy and power grids overview in Northwest China and Arab States

2.1. Xinjiang of China

Xinjiang Uyghur Autonomous Region is positioned as China's 'National Energy Strategy Base' because of its rich energy resources, accounting for more than 20% of China's total reserves of natural gas, coal, and other fossil resources. Also, Xinjiang's wind power and solar energy resources are ranked second in the country, while its theoretical hydropower reserves rank fourth [7].

At the end of 2015, the installed generating capacity of Xinjiang is 65.7GW, of which coal accounts for 56.3%, wind accounts for 25.7%, and solar energy and hydropower each account for 8% according to the data from State Grid Corporation of China (SGCC). As the exploitation and utilization of renewable energy has rapidly supported by Chinese government, Xinjiang will continually feature larger scale of clean energy.

Currently, a strong 750kV power grid backbone has been formed within Xinjiang which has further extended to interconnect with northwest main grid. And as the ± 800 kV Hami–Zhengzhou UHVDC transmission line putting in operation in early 2014, the electricity import and export of Xinjiang has been increased significantly.

2.2. Iran

Islamic Republic of Iran is an energy superpower. As a founding member of the Organization of the Petroleum Exporting Countries (OPEC) and Gas Exporting Countries Forum (GECF), Iran has the second largest proved gas reserves and also ranks fourth in oil reserves in the world¹, but the country has relied heavily on its rich fossil fuel resources to supply domestic energy consumption. In 2014–2015, as the most common generating feedstock, natural gas contributed to approximately 70% of Iran's total energy generation, with the remaining share provided by coal, hydropower, nuclear and other renewable sources [8]. The Iranian government has signalled its intention to move towards a more balanced energy mix while improving energy efficiency, and a special premium has been placed on hydropower since it is the country's largest renewable resource by generational capacity; moreover, Iranian companies have considerable experience in hydropower development.

Promising to become the power hub of Western Asia, Iran has been exporting surplus electricity to several neighbouring countries including Iraq, Turkey and Pakistan, and has an increasing electricity-exporting demand for economic growth.

2.3. Gulf Cooperation Council (GCC)

The Gulf Cooperation Council (GCC) regional market was established in 1981 by a cooperation agreement between six Arab states of the Persian Gulf, i.e., Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates (UAE).

Despite the fact that the GCC states control 40% of the world's crude oil reserves and 25% of its gas reserves, rising population and wasteful consumption threaten to create acute shortages of GCC energy exports. Demand for electricity, which is typically generated by natural gas, is already outstripping domestic supply in the GCC states, requiring substantial investment in generation

¹ Source: World Bank, 2016.

capacity [9–11]. According to Arab Union of Electricity (2015), a power deficit of more than 60GW is predicted by 2020.

The GCC states have made significant progress integrating their electricity networks to facilitate cross-border trade. The 400kV GCC interconnection super grid connects the electrical power networks of all the six countries and aims at capacity reserve sharing and improved supply reliability [12,13].

3. China-Arab power transmission planning

The planning construction year is set to 2030. Currently, the proposed China-Arab transnational interconnection considers Xinjiang as the starting point for its rich natural resources, enhanced electricity-exporting capability, and huge potential of renewable energy exploitation; GCC region as the receiving end given its ongoing resource shortage and rapidly growing demand of electricity. Besides, an additional link between Iran and GCC region will be arranged in order to meet Iran's electricity-exporting needs.

3.1. Sending-end power source mix and landing point selection

Yili area, one of the large-scale coal and clean energy bases in Xinjiang, is selected to house the sending-end converter station, transmitting power generated from a balanced combination of hydropower, coal and wind energy to GCC region.

The landing point of receiving-end is Kuwait, situated in the northern edge of GCC region and connected to the GCC interconnection network at 50Hz, 400kV. Meanwhile, Ahvaz, the largest city of the Iranian hydropower base in Khuzestan, is chosen as the starting point of the Iran-GCC link to transmit surplus hydroelectric power to GCC states.

3.2. Transmission corridor route planning

Based on the electricity demand and supply analysis, the proposed China-Arab transmission link consists of two subprojects: subproject 1 links Yili and Kuwait while subproject 2 links Ahvaz and Kuwait, in an attempt to optimize the distribution of energy resources in these regions.

As shown in Figure 1, the blue line denotes the Yili-Kuwait point-to-point link which starts at the Yili converter station in Xinjiang, running along Central Asia through Kazakhstan, Uzbekistan, Turkmenistan, Iran, and Iraq to Kuwait converter station in GCC region. By taking full advantage of Ahvaz being situated along the Yili-Kuwait transmission corridor, Ahvaz-Kuwait link (see green line in Figure 1) starts at the Ahvaz converter station and takes the same route as the following part of subproject 1.

Since the border of Xinjiang and Kazakhstan as well as western part of Iran covers mountainous areas, the overall transmission distances of two subprojects are calculated as 4140km and 300km respectively by introducing an average tortuous coefficient of 1.2.

3.3. Transmission system configuration

For Yili-Kuwait link with a transmission length of 4140km, UHVDC scheme is the most economically attractive and environmentally friendly solution for bulk power transmission over such a long distance. According to [14], this line will operate at 1100kV DC voltage in bipolar mode and is designed to have a transmission capacity of 10GW. For the purpose of keeping the power loss within reasonable range, 8×1000mm² transmission cable is selected. Furthermore, at the two terminals of the link, Yili converter station will be connected to the nearby 750kV Yili power station by four-circuit 100km long AC lines, and the receiving-end Kuwait converter station will be connected to local AC system by 8-circuit 50km long 400kV AC lines to three power stations around Kuwait City, which are then connected to the GCC interconnection network.

It would be most suitable for the 300km long Ahvaz-Kuwait link to adopt a DC voltage at ±350kV with 800MW rated capacity, utilizing 4×400mm² transmission cable. Ahvaz converter station will be connected to the 230kV Ahvaz substation by double-circuit 50km long AC lines while Kuwait

converter station will be connected to the 275kV substation by double-circuit 50km long AC lines. Table 1 summaries the overall system configuration of the proposed China-Arab transmission project.

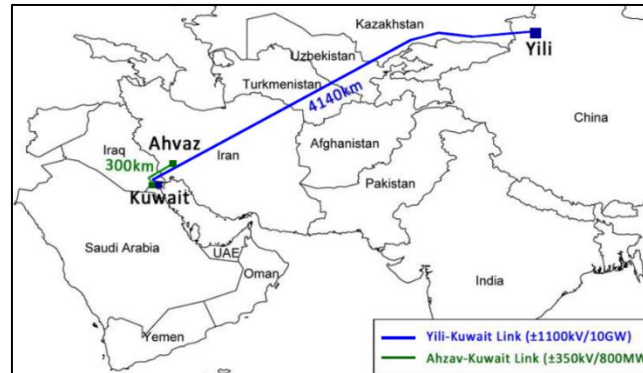


Figure 1. Corridor planning of China-Arab transmission

Table 1. System configuration of China-Arab transmission

Subsystem	Voltage	Capacity	Distance	Converter Transformers	
Yili-Kuwait Link	$\pm 1100\text{kV}$	10GW	4140km	Yili 1100kV DC/750kV AC	Kuwait 1100kV DC/400kV AC
Ahvaz-Kuwait Link	$\pm 350\text{kV}$	800MW	300km	Ahvaz 350kV DC/230kV AC	Kuwait 350kV DC/275kV AC

4. Static costs estimation of China-Arab transmission project

4.1. General principle of costs estimation

The primary aim of power transmission project costs control is to manager static costs because dynamic costs are influenced by market prices fluctuation and thus are normally unpredictable [15].

For overhead transmission line, the fixed one-time capital costs play the dominant role in total static costs (typically at 65%-75%) and show little divergence between different systems under similar environmental conditions, while the remaining part (costs of auxiliary facilities, construction sites requisition, etc.) can vary from different states and regions, especially in transnational cases. As a result, analogy cost estimating technique is firstly adopted to estimate the capital costs of the proposed China-Arab interconnection project, based on existing transmission systems similar in design and operation (for example, operating at the same voltage level) as well as others that are currently under construction or have completed the pre-feasibility study. For the sake of accounting for differences, adjustments are made through the use of scaling factors that represent differences in the ratio of static costs to capital costs, size, latitude, topography and economy.

4.2. Static costs estimation

The costs of point-to-point HVDC project can be divided into three elements: transmission works, converter stations at terminals and associated AC substation extensions [16,17].

The capital costs of transmission and converter stations involved in the $\pm 1100\text{kV}$ Yili-Kuwait link are estimated with reference to the feasibility studies of the following two $\pm 1100\text{kV}$ UHVDC projects: China's Zhundong-Wannan transmission project [18,19] and Asia-Europe intercontinental transmission planning [20,21], while the $\pm 350\text{kV}$ Ahvaz-Kuwait link takes New Zealand's HVDC Inter-Island Link Upgrade Project [22] and Africa's Caprivi HVDC Link [23–26] as analogous systems. In terms of connecting converter stations into existing AC networks, AC extensions costs will count in the construction of new AC lines and switchyards, as well as the installation of series capacitors, estimated based on similar operational projects [27–31].

Table 2 and 3 give the estimated static costs of each component for two links respectively, which are subsequently used for preliminary investment estimation and further analysis of financial evaluation.

Table 2. Static costs estimation of each component for Yili-Kuwait Link ($\pm 1100\text{kV}/10\text{GW}$)

	Item	Unit Static Cost
Converter Stations	Yili Rectifier Station	\$106.19 /kW
	Kuwait Inverter Station	\$116.83 /kW
DC Transmission	China	\$1.53M/km
	Kazakhstan, Uzbekistan, Turkmenistan, and Iran	\$1.31M/km
	Iraq, Kuwait	\$1.09M/km
	750kV Single-Circuit AC Lines	\$0.49M/km
AC Substation Extensions	400kV Single-Circuit AC Lines	\$0.32M/km
	750kV Switchyard	\$115.8M
	Series Capacitors	\$32/kVA

Table 3. Static costs estimation of each component for Ahvaz-Kuwait Link ($\pm 350\text{kV}/800\text{MW}$)

	Item	Unit Static Cost
Converter Stations	Ahvaz Rectifier Station	\$181.37/kW
	Kuwait Inverter Station	\$181.37/kW
DC Transmission	Iran	\$0.32M/kW
	Iraq and Kuwait	\$0.27M/kW
	230kV Single-Circuit AC Lines	\$0.16M/km
AC Substation Extensions	275kV Single-Circuit AC Lines	\$0.13M/km
	230kV Switchyard	\$13.46M
	Series Capacitors	\$27.7/kVA

According to system configuration, corridor planning and unit cost estimation presented above, the total static costs of the proposed China-Arab transnational transmission project are listed in Table 4, under the assumption that two groups of series capacitors will be installed for both subprojects and the reactive power is rated at 600Mvar and 100Mvar per group for Yili and Ahvaz substations respectively.

5. Future outlook on China-Arab power transmission link

It is worth noting that the static costs estimating model employed in this paper only takes account of fixed production and construction expenditures needed to bring the proposed transmission project into an operable status, however, the long-term operating and maintenance costs as well as contingencies that would occur in the full designed operating period will be further exploited in the following financial appraisal works. The next course of action will involve:

- Alternative transmission schemes and power supply combination (different transmission corridor routes, various voltage and size ratings, etc.);
- Reliability assessment for each transmission scenario (important factors such as power transmission loss, voltage support ability of receiving end networks);
- The transmission tariff competitiveness and financial evaluation of each transmission scheme, providing indicators to select the most optimal scheme;

- Sensitivity analysis of financial feasibility factors for selected transmission cases (such as tariff, customs rate, cost estimation fluctuations).

Table 4. Total static costs estimation of China-Arab transmission project

Items	Yili-Kuwait Link ($\pm 1100\text{kV}/10\text{GW}$)	Ahvaz-Kuwait Link ($\pm 350\text{kV}/800\text{MW}$)
Converter Stations Costs	\$2.23B	\$0.29B
AC Substation Extensions Costs	\$0.48B	\$0.05B
DC Transmission Costs	\$5.55B	\$0.09B
Total Static Costs	\$8.25B	\$0.43B
	\$8.68B	

6. Conclusion

This paper aims to present an outlook on a transnational power interconnection between China and Arab, echoing with the international effort of pursuing sustainable development of the world's energy resources from a global perspective. The energy and electricity demand and supply research confirmed the power-exporting capacity of the sending-end and the growing electricity demands of the receiving-end. The proposed transmission project consists of $\pm 1100\text{kV}/10\text{GW}$ Yili (China)-Kuwait UHVDC link and $\pm 350\text{kV}/800\text{MW}$ Ahvaz (Iran)-Kuwait HVDC link, over distances of 4140km and 300km respectively. The total static costs have been preliminarily estimated at 8.68 billion dollars and will be used in further financial evaluation.

Given that part of the Arabian world has already integrated into the European super grid, the impact of the proposed China-Arab interconnection can go beyond Asia. It could serve as one of the key links for a potential global network interconnection and contribute to the development of UHV based and green energy concentrated power transmission technology.

Acknowledgments

The paper is funded by project "Feasibility Study on Interconnection of Arabian Power Grid" of State Grid Corporation of China.

References

- [1] Liu Z 2015 A Global Energy Outlook *Global Energy Interconnect* (New York: Academic Press, 2015) chapter 3 pp 91-100
- [2] Liu Z 2015 Innovation in Global Energy Interconnection Technologies *Global Energy Interconnect* (New York: Academic Press, 2015) chapter 6 pp 239-72
- [3] Li G, Li C and Hertem DV 2016 HVDC Technology Overview *HVDC Grids: For Offshore and Supergrid of the Future* (New York: John Wiley & Sons Incorporated).
- [4] Molburg JC, Kavicky JA and Picel KC 2007 The design, construction, and operation of long-distance high-voltage electricity transmission technologies *Power Transmission & Distribution*
- [5] Åström U, Weimers L, Lescale V and Asplund G 2005 Power transmission with HVDC at voltages above 600 kV *Proc. Conf. on Power Engineering Society Inaugural Conference & Exposition (Africa)* pp 44-50
- [6] Åström U, Lescale VF, Menzies D and Ma W 2010 The Xiangjiaba-Shanghai 800 kV UHVDC project, status and special aspects *Int. Conf. on Power System Technology* pp 1-6
- [7] Duan J, Wei S, Zeng M and Ju Y 2016 The energy industry in xinjiang, china: potential, problems, and solutions *Power* **160** 1 52-3
- [8] Central Bank of the Islamic Republic of Iran 2016 *Annual Review (2014/15)* (Tehran: The Central Bank of the Islamic Republic of Iran issues Press).

- [9] The World Bank 2013 *Middle East and North Africa Integration of Electricity Networks in the Arab World: Regional Market Structure and Design*
- [10] Dargin J 2010 *The GCC in 2020: Resources for the future* (The Economist Intelligence Unit) pp 1-27
- [11] Krane J 2013 *Energy Policy in the Gulf Arab States: Shortage and Reform in the World's Storehouse of Energy* (Cambridge University)
- [12] Economic Consulting Associates 2010 *The Potential of Regional Power Sector Integration: Gulf Cooperation Council Countries Transmission and Trading Case Study* Energy Sector Management Assistance Program (Washington, DC: World Bank)
- [13] Ahmad A and Babar M 2013 Effect of Energy Market Globalization over Power Sector of GCC Region: A Short Review *Smart Grid and Renewable Energy* **4** 3 42-60
- [14] Liu ZY, Shu YB, Zhang WL and Zhang YZ 2008 Study on Voltage Class Series for HVDC Transmission System *Proc. of Chinese Society For Electrical Engineering* **28** 1-8
- [15] Tan YG 2009 Analysis on the overhead transmission line project cost control *Chinese Hi-tech Enterprises* 144-145
- [16] Pletka R, Khangura J, Rawlines A, Waldren E and Wilson D 2014 Capital Costs for Transmission and Substations *Western Electrical Coordinate Council* 35
- [17] Pérez-Arriaga IJ 2010 *Electricity transmission: Investment* Open Course Ware (Cambridge: Massachusetts Institute of Technology).
- [18] Yang WK, Yin YH, Ban LG and Zeng NC 2015 Study on 1100 kV UHVDC System Commissioning Test Program *Power System Technology* **39** 2815-21
- [19] Wang YT, Zhang YC, Guo XJ, Shen C and Qiao HH 2016 A Study on System Connection Schemes for 1100kV UHVDC Sending and Receiving Ends *Power System Technology* **40** 1-7
- [20] You PY, WANG XH and Zhang Y 2015 Economic Research on Asia-Europe Long-Distance UHV Power Transmission *Power System Technology* **39** 2087-93
- [21] Zhang YT, Zhang ZQ, Zhang YH and Liang CH 2015 Application Research on UHVDC Technology in Asia-Europe Power Transmission Planning *Power System Technology* **39** 2069-75
- [22] Transpower New Zealand Limited 2005 *HVDC Inter-Island Link Upgrade Project: Investment Proposal* (New Zealand)
- [23] Magg TG, Mutschler HD, Nyberg S, Wasborg J, Thunehed H and Sandberg B 2010 *Caprivi Link HVDC Interconnector: Site selection, geophysical investigations, interference impacts and design of the earth electrodes* Conference International des Grands Reseaux Electriques
- [24] School of Engineering Namibia 2012 *INDUSTRIAL EXCURSION REPORT: Gerus HVDC Converter Station*
- [25] Magg T, Manchen M, Krige E, Wasborg J and Sundin J 2012 Connecting networks with VSC HVDC in Africa: Caprivi Link Interconnector *IEEE PES Power Africa 2012 Conf. Expo.*
- [26] EU-Africa Infrastruct. Trust Fund 2012 *Project Completion Report: The Caprivi Interconnector* (Namibia) 1-10
- [27] East China Electric Power Design Institute 2014 *Environmental Impact Report on 500kV Boyang Transmission Project* 1-12
- [28] Northwest Electric Power Design Institute 2014 *Environmental Impact Report on 750kV Xinjiang Wucaiwan-Jijihu-Santanghu Transmission Project* 1-120
- [29] China Guodian Environmental Protection Academy 2015 *Environmental Impact Report on 750kV Qinghai Haixi-Main Grid Transmission Capacity Enhancement Project* 1-16
- [30] Southwest Electric Power Design Institute 2016 *Environmental Impact Report on 750kV Yuka Switchyard Expansion Project* 1-12
- [31] Nie J 2013 Analysis of the 220kV grid projects costs in southern Hebei *Management Science* 105-106