Global Smart Grid Transmission: Comparison of Europe, the U.S., and China

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Global Smart Grid Transmission: Comparison of Europe, the U.S., and China

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Abstract— The paper tries to address the question of whether the smart grid solution can be transited internationally, and explore the possibility of international transition with three national comparisons: USA, Europe, and China. A qualitative content analysis in which data (the academic papers) are coded in preparation for comparison and interpretation is chosen to find the similarities and differences of smart grid development in different national context. Trough a comparative analysis of smart grid development in USA, Europe and China, this paper conducts a transferable framework of smart grid solution with global and local features.

Keywords: smart grid, cross-national comparison, globalization

INTRODUCTION

Smart grid is an upcoming technology being applied currently in developed countries, e.g. US, EU, Japan [1]. Many developing countries, such as China, Africa and Thailand, are all aware the important and start to develop this area, e.g. Sebitosi and Okou [2]. According to Hashmi, Hanninen, and Maki [3], "the definition of smart grid can also depend on local conditions; different countries can have very different starting points for the process towards smart grid". Smart grid development appears differently in many interesting ways when compared with other countries [4]. The main challenge of the global smart grid solution can be argued as readiness of utilities, ICT and stakeholder management. For instance, smart grid technologies are mainly deployed with regional, country, or utility specific objectives and requirements, to be quantified in the areas of environmental goals, security of electricity supply, and macro-economic growth and business sustainability development [5].

However, this paper argues that the global drivers and challenges provide a possible platform for the international transition of the smart grid solution, such cross-national technological and managerial transfer. The global smart grid market has huge potential due to the enormous market need. However, the global smart grid solution is more complex compared to the general smart grid solution, which not only interrelates utility readiness and variable factors' embeddedness, but also requires tailor-made strategies for specific national market needs. Despite the recognition of the importance of the smart grid globalization, there has been little research to provide the smart grid solution for dynamic markets.

Plenty of research has done comparative studies of the smart grid development with the national or cross-national aspects, e.g. [6-9]. Majority of the research focuses on the technological aspect, and little has stated the correlation across countries or the management aspect. In order to fill the gap, this paper seeks to examine the question of whether the smart grid solution can be transited internationally, and what are the impact factors. To address this question, this research tries to compare the current smart grid situation, and also provide insights into the managerial perspective of smart grid. USA, Europe and China are selected for the represented countries, which represent a spectrum of diverse political, economic, environmental and technological situations with different smart grid foci.

Despite the widespread impact of cross-national comparative research on smart grid, it is surprising that the current comprehensive reviews are rather limited, which has resulted in a large body of literature that lacks integration. The proliferation of smart grid research made it necessary to develop specific criteria to limit the scope of our review. In addition, the smart grid literature spans diverse disciplines, such as academic papers, government and industry reports. Thus, we limited our focus to articles published in IEEE Xplore and Google scholar database. We also extended the review by searching the references of articles returned in our first search to identify additional articles. We recognize that many studies use different terms, so we searched for articles that use the term of "smart grid + country/ nation/ international/ America/ Europe/ China". In cases where a relatively large number of studies share a common theme, we have included a sampling of those that are indicative of the national context of the U.S., Europe and China. We found 28 articles that met our search criteria, summarized in Table 1.

In order to fill the gap of the sidedness of the current cross-national smart grid research which mainly focuses on the technological aspect. We describe each theme found in the coding and draw conclusions from them. Second, we discuss the missing part in the current cross-national smart grid research, and bring attention to the importance of the international transition of the smart grid solution. Finally, we offer recommendations to build on this body of research.

Citation	Topic area
[10]	China
[11]	China
[12]	China
[13]	China, India and Brazil
[14]	China, the U.S. and Europe
[15]	China, the U.S., Europe
[16]	The U.S., EU, and China
[7]	UK and China
[17]	The U.S. and global
[18]	The U.S., Brazil
[19]	Europe, the U.S.
[20]	The U.S.
[21]	Europe, Czech Republic
[22]	Denmark
[9]	Europe: Belgium, Germany, Italy and Spain
[23]	Germany
[24]	Germany
[25]	Sweden
[26]	Northern Isles
[27]	Spain
[28]	Europe
[8]	Germany and Russia
[29]	Europe
[30]	Netherlands
[31]	Denmark
[32]	Lation American: Brazil, Colombia. Chile.
[6]	UK, Denmark, France, the U.S.
[3]	EU, USA

Table 1. Overview of the national/cross-national research on Smart Grid

COMPARATIVE STUDY

The smart grid development is diverse in different countries due to different situations. Apparently there are different timelines and focuses. For instance, China officially announced the smart grid plan and development in 2009 by the East China Power Grid Company [15] [16]. Compared to China, the U.S. has much longer history of smart grid development. The significant efforts in the U.S. have been dedicated to develop new technologies since 1980s [16] and the U.S. Smart Grid Initiative is the official policy of grid modernization as formalized by the 2007 [19].

In this paper, these social aspects are described as the social circumstance of the smart grid development and compared between Europe, the U.S. and China. By summarizing the literature, the circumstance of the smart grid development can be divided into market, economy, policy (including rules, regulations, and standardization), and energy resource. These elements decide the direction and focus of a national smart grid initiative and development. For instance, the geographic diversity and economic imbalance drives both Europe and China to focus the transmission and integration of the smart grid development. However, the global pressure, economic growth and society demand makes China more concern the strong and reliable, efficient and economical power grid.

Most national/cross-national research on the smart grid development focuses on the technological aspect, and this research tries to figure out the differences and similarities of the smart grid technology development in China, Europe and the U.S., which is described as the construction of smart grid development in this paper. According to the 28 articles, the main elements of smart gird construction are: transmission, distribution, ICT, energy storage, and operations.

DISCUSSIONS

According to the literature analysis, this paper identified eleven elements (six elements in the social aspect and five elements in the technological aspect) that have been popularly discussed in the comparative/national smart grid studies. Although the technological aspect has been discussed in many papers, this paper still tried to discuss both social and technological aspects with a new form to present an integral picture. Some articles have mentioned and primarily discussed few social elements, e.g. Fang, Misra, Xue and Yang [33]. However, some important social elements are still missing. For instance, the framework [33] misses the political, economic and market elements.

Majority of current research focuses on the "comparison" between countries. Meanwhile, there is limited research present the similarity and dissimilarity of smart grid development across countries. This paper argues that the similarity and dissimilarity is important for the smart grid technology and knowledge transfer across countries. Also, the across-national collaboration is the only solution for the global energy issues. The first step for the across-national smart grid collaboration is the similarity/ dissimilarity understanding, and then it can find the collaboration possibility and focus area. Table 2 and table 3 show the example of element comparison between Europe, the U.S. and China. Taking the market element for example, both Europe and the U.S. concern the standardization, but not in China. There are several reasons behind, and it also indicates collaboration opportunity regarding standardization, such as experience transfer from Europe to China.

This paper found that some elements are missing in the current smart grid comparison studies, which are important for the international smart grid collaboration. These elements can be defined as: demographic, geographic, and cultural elements. For instance, the geographic situation of economics and energy resources influences the policies or national strategies for the smart grid development. China has high interest and focus on the ultra-high voltage power grid transmission due to the unbalanced energy resources and economic development.

This paper argues that it is important to have a big picture of the smart grid development across countries. The scale and focus of the national smart grid should be presented under the global smart grid structure. It is no doubt that the worldwide smart grid direction is transforming the traditional energy system to the entirely smart energy system, and with the dimension of national scale and focus. Taking the stakeholder dimension as example, there should be a fully active stakeholder participation to support the entire smart energy system. At this dimension, Denmark is more advanced than the U.S. and China.

Country		Europe	U.S.	China
Social aspects	Economy	• Long-term • Low carbon economy • Sustainable economy (renewable source) • Energy saving	• Long-term • Security technology demand growth	• Economy high speed growth • Electricity demand • Low carbon economy • Global warming-renewable power
	Policy & regulation	• Discussion facilitation • Common standard establishment • Diversity across countries	• Framework and principle of smart grid development • Emergence of standards and information exchange • Stakeholders' education and involvement • Research support	• Central government-related national plan, law, and incentives • Local government: incentives • Overlapping authorities and unclear power structure
	Energy resources	• Traditional fossil energy • High import reliance • Diversified energy mix • Different renewable energy conditions	• Large production of hydroelectric power • Large capacity of wind power • Expected power generation: 25% is renewable resources, 18% is coal, 53% is natural gas	• Abundant renewable energy resources, e.g. solar and wind power • Coal-dominated energy consumption structure (68.9% coal, 21% oil)
	Market	• Regulated and liberalized regimes coexist • Complex situation across European energy markets • High demand of Data exchange and **standardization** • Power market completion • User satisfaction pressure	• Dynamic **pricing** in the bulk power market • Industry deregulation • Moving towards less-centralized consumer interactive systems • **Standardization** concern	• Uncompleted formed national electricity market • Unopened electricity **price** • Limited demand side management • Limited customer participation • Future environmental cost addition
	Stakeholder	In liberalized energy countries: • Bottom-up approach • Consumer involvement • Decentralized responsibilities • Municipal and consumer-owned network operators In centralized energy countries: • Strong role of network operators	• Vertically integrated electric utilities • Strong role of network operator • Little attention on new smart grid actors	• Key stakeholders: Chinese government, power grid companies, global/local equipment& service providers • Neglected role of end consumers
	Smart grid solution	• User-central technologies, product and service, e.g. smart metering • Customer interaction • Internet connection	• Challenges of smart meter installation due to electricity bill increase and information privacy	• Customers' demand on: higher service quality, flexibility of power supply choices • Lack of intelligent electricity consumption

Table 2. Social aspect comparison across Europe, the U.S., and China

Country		Europe	U.S.	China
Technical aspects	Transmission	• Distribution network including the demand side • Integration of renewable energy resource • Expansion of transmission and distribution network • Pioneering concepts of system control and operation	• Complex situation • Transmission failure experience Wide-area measurement and fast control • Several types of device installation	• Ultra-high voltage power grid transmission • Various power system condition in different areas
	Distribution	• "Energy-efficient Europe" • Reliable, safer, and sustainable energy supply system • Distributed generation integration • Decentralized intelligence in distribution grid		• Priority in constructing smart distribution grid • Imbalance in the energy resource distribution • Large-scale power flows required • Efficiency of energy resource in western region required • Technical aspect focus
	ICT & platform	• Integration to whole EU smart grid network • Conjunction with market understanding, and customer demand • Communication technologies • Demand response management • Market-based platform	• Security concern • Poor communication • Responsiveness to predicted growth and demand required • Digitalization required	• Lack of construction and related technology
	Energy storage & equipment		• Energy storage at distribution level • Incorporation of renewable resources and energy resource • Standardization of equipment interoperability • Smart consumer devices emphasized	• Advanced equipment and technology • Challenge in energy storage and other technologies widely used • Supporting equipment construction required
	Operations	• Operation efficiency improvement • Customer interaction • Electricity price reduction • Various stakeholders' roles	• Dynamic optimization of grid operations • Power quality, reliability, and security • Environmental protection policy	• Security monitoring technology

Table 3. Technological aspect comparison across Europe, the U.S., and China

CONCLUSIONS

The research findings show that there are some missing aspects for the global smart grid research. Based on the limitation of current research, we suggest that the following aspects require more focus in the future research:

- *Systematic research on cross-national smart management system*: The current cross-national smart grid research hasn't provided a systematic, overall view with the whole picture integrating social and technological aspects. Therefore, a tool or database is recommended for the future research. Meanwhile a template is recommended for the systematic comparative studies.
- *The global-local smart grid solution*: Current research mainly focuses on the cross-national comparison or international collaboration. Our research findings show that there are similarities and differences across national smart grid environment and development. Therefore, it is necessary to integrate global and local aspects for the further smart grid solution.
- *Correlation between different systems and aspects*: This research found that the social factors impact on the national technological development of smart grid. Meanwhile, the research also argues that the correlations might be different across countries. Therefore, the further research is recommended to explore it.
- *Cultural impact on the national smart grid development*: In the comparison, this research found that the focuses of smart grid development are different even inside Europe. The social responsibility and ethical principle of governments and citizens influence the smart grid development. For instance, Denmark plans to have 100% renewable energy in 2050, and the high electricity price (including tax and research and development) is more acceptable for households in Denmark. Therefore, more research is expected to explore the cultural impact to the global smart grid development.

REFERENCES

[1] A. Jirapornanan, *Study of Smart Grid for Thailand and Identification of the Required Research and Development*. New York: Ieee, 2010.

[2] A. B. Sebitosi and R. Okou, "Re-thinking the power transmission model for sub-Saharan Africa," *Energy Policy,* vol. 38, pp. 1448-1454, Mar 2010.

[3] M. Hashmi, S. Hanninen, and K. Maki, "Survey of smart grid concepts, architectures, and technological demonstrations worldwide," in *Innovative Smart Grid Technologies (ISGT Latin America), 2011 IEEE PES Conference on*, 2011, pp. 1-7.

[4] D. N. Y. Mah, J. M. van der Vleuten, P. Hills, and J. Tao, "Consumer perceptions of smart grid development: Results of a Hong Kong survey and policy implications," *Energy Policy,* vol. 49, pp. 204-216, Oct 2012.

[5] B. Wojszczyk, "Deployment of advanced Smart Grid solutions - Global examples and lessons learned," in *Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES*, 2012, pp. 1-1.

[6] C. Brandstatt, N. Friedrichsen, R. Meyer, and M. Palovic, "Roles and responsibilities in smart grids: A country comparison," in *European Energy Market (EEM), 2012 9th International Conference on the*, 2012, pp. 1-8.

[7] S. Qiang, W. Jianzhong, Z. Yibin, N. Jenkins, and J. Ekanayake, "Comparison of the development of Smart Grids in China and the United Kingdom," in *Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES*, 2010, pp. 1-6.

[8] N. Moskalenko, Z. A. Styczynski, T. Sokolnikova, and N. Voropai, "Smart Grid- German and Russian perspectives in comparison," in *Modern Electric Power Systems (MEPS), 2010 Proceedings of the International Symposium*, 2010, pp. 1-7.

[9] A. Cronenberg, A. Delnooz, C. Linke, M. Baron, O. Lago, and P. Linares, "How do the benefits from active demand vary? A comparison of four EU countries," in *Energy Conference and Exhibition (ENERGYCON), 2012 IEEE International*, 2012, pp. 693-700.

[10] R. Zhang, Y. Du, and Y. Liu, "New challenges to power system planning and operation of smart grid development in China," in *Power System Technology (POWERCON), 2010 International Conference on*, 2010, pp. 1-8.

[11] L. Jie, C. Qi, and Y. ShenChun, "The constructive situation and developing direction of the electricity consumption information collection system in China," in *Electricity Distribution (CICED), 2012 China International Conference on*, 2012, pp. 1-8.

[12] G. Haochi, Z. Mingming, and K. L. Lo, "Long Term Energy Scenario for China," in *Power and Energy Engineering Conference (APPEEC), 2010 Asia-Pacific*, 2010, pp. 1-7.

[13] M. F. Nejad, A. Saberian, H. Hizam, M. A. Mohd Radzi, and M. Z. A. Ab Kadir, "Application of smart power grid in developing countries," in *Power Engineering and Optimization Conference (PEOCO), 2013 IEEE 7th International*, 2013, pp. 427-431.

[14] L. Siming, C. Yunhui, H. Jing, F. Yongding, L. Bangfeng, H. Hui*, et al.*, "Discussion on Smart Grid Development in China," in *Power and Energy Engineering Conference (APPEEC), 2011 Asia-Pacific*, 2011, pp. 1-4.

[15] L. Jingjing, X. Da, and A. Qian, "Research on smart grid in China," in *Transmission & Distribution Conference & Exposition: Asia and Pacific, 2009*, 2009, pp. 1-4.

[16] B. Tianshu, L. Sumei, H. Zhenyu, and N. Hadjsaid, "The implication and implementation of smart grid in China," in *Power and Energy Society General Meeting, 2010 IEEE*, 2010, pp. 1-5.

[17] L. Siou-Zih, C. Ssu-Han, W. Chun-Chieh, and C. Dar-Zen, "A comparison of technology trajectories between the global and the United States in smart grid," in *Industrial Engineering and Engineering Management (IEEM), 2011 IEEE International Conference on*, 2011, pp. 1028-1032.

[18] S. Suryanarayanan, P. F. Ribeiro, and M. G. Simoes, "Grid modernization efforts in the USA and Brazil - some common lessons based on the Smart Grid Initiative," in *Power and Energy Society General Meeting, 2010 IEEE*, 2010, pp. 1-5.

[19] M. G. Simoes, R. Roche, E. Kyriakides, S. Suryanarayanan, B. Blunier, K. D. McBee*, et al.*, "A Comparison of Smart Grid Technologies and Progresses in Europe and the U.S," *IEEE Transactions on Industry Applications,* vol. 48, pp. 1154-1162, 2012.

[20] P. Joskow, "creating a smarter U.S. electricity grid," *Journal of Economic Perspectives,* vol. 26, pp. 29-48, 2012.

[21] O. Malik and P. Havel, "Analysing demand-side management potential: Situation in Europe and the Czech Republic," in *Environment and Electrical Engineering (EEEIC), 2011 10th International Conference on*, 2011, pp. 1-4.

[22] J. R. Pillai, H. Shaojun, P. Thogersen, J. Moller, and B. Bak-Jensen, "Electric vehicles in low voltage residential grid: A danish case study," in *Innovative Smart Grid Technologies (ISGT Europe), 2012 3rd IEEE PES International Conference and Exhibition on*, 2012, pp. 1-7.

[23] M. Wissner, "ICT, growth and productivity in the German energy sector – On the way to a smart grid?," *Utilities Policy,* vol. 19, pp. 14-19, 1// 2011.

[24] R. Hollinger and T. Erge, "Integrative energy market as system integrator of decentralized generators," in *European Energy Market (EEM), 2012 9th International Conference on the*, 2012, pp. 1-6.

[25] C. J. Wallnerstrom and L. Bertling, "Learning from experiences of the prior Swedish electrical distribution system regulation — Reference material when developing the future regulatory incentives," in *Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES*, 2010, pp. 1-8.

[26] M. J. Dolan, G. W. Ault, D. F. Frame, S. Gill, I. Kockar, O. Anaya-Lara*, et al.*, "Northern Isles New Energy Solutions: Active network management stability limits," in *Innovative Smart Grid Technologies (ISGT Europe), 2012 3rd IEEE PES International Conference and Exhibition on*, 2012, pp. 1-9.

[27] A. Sendin, I. Berganza, A. Arzuaga, A. Pulkkinen, and K. Il Han, "Performance results from 100,000+ PRIME smart meters deployment in Spain," in *Smart Grid Communications (SmartGridComm), 2012 IEEE Third International Conference on*, 2012, pp. 145-150.

[28] Y. Ding, S. Pineda, P. Nyeng, J. Ostergaard, E. M. Larsen, and Q. Wu, "Real-Time Market Concept Architecture for EcoGrid EU—A Prototype for European Smart Grids," *Smart Grid, IEEE Transactions on,* vol. PP, pp. 1-11, 2013.

[29] L. Ardito, G. Procaccianti, G. Menga, and M. Morisio, "Smart Grid Technologies in Europe: An Overview," *Energies,* vol. 6, pp. 251-281, 2013.

[30] L. O. AlAbdulkarim and Z. Lukszo, "Smart metering for the future energy systems in the Netherlands," in *Critical Infrastructures, 2009. CRIS 2009. Fourth International Conference on*, 2009, pp. 1-7.

[31] X. Zhao, M. Gordon, M. Lind, and J. Ostergaard, "Towards a Danish power system with 50% wind - Smart grids activities in denmark," in *Power & Energy Society General Meeting, 2009. PES '09. IEEE*, 2009, pp. 1-8.

[32] V. J. Martinez and H. Rudnick, "Design of Demand Response programs in emerging countries," in *Power System Technology (POWERCON), 2012 IEEE International Conference on*, 2012, pp. 1-6.

[33] X. Fang, S. Misra, G. Xue, and D. Yang, "Smart Grid -The New and Improved Power Grid: A Survey," *Communications Surveys & Tutorials, IEEE,* vol. 14, pp. 944-980, 2012.