The International Journal of Engineering and Science (IJES)
|| Volume || 7 || Issue || 9 Ver.III || Pages || PP 10-15 || 2018 ||
ISSN (e): 2319 – 1813 ISSN (p): 23-19 – 1805

Investigation On Tie-Line Power Control Strategy Of HVAC-HVDC Hybrid Power System Of Northern China

Jian.LIU[1]Xiaodong. NIU[1] Lei. GUO*[2]ShangGuang. Jiang[2]

School of Economics and Management，North China Electric Power University，ChangpingDistrict,Beijing 102206，China ；2.North China Power Dispatching and Control Centre,Xicheng District,Beijing 100053,China;）
Corresponding Author: Jian.Liu

--*ABSTRACT*--

As the economy of China and living standards of Chinese people increase rapidly, the power consumption sees fast growth as well. Long-distance and high-capacity power transmission via HVDC has become a widely-accepted power delivery solution, since China features uneven distribution of natural resources, and the load center is far away from power generation places. North China Power Grid (NCPG) is known as one of the six regional power grids in China. In recent years, NCPG has staged a remarkable transformation, from early-period HVAC to present-day HVDC, from early-period small amount of renewable power sources, to present-day large-scale penetration of renewable energy. This paper examines the historical variations of control strategies adopted by NCPG, and investigates the weakness of these control strategies under current power system conditions. Based on the investigation, new optimization methods of frequency and tie-line power control are proposed to enhance thepower handling capability of NCPG as a large-scale power grid.

KEYWORD:*Ultra-high voltage, AC-DC hybrid system, renewable energy, automatic generation control, control strategy*

Date of Submission: 06-09-2018 Date of acceptance: 22-09-2018

I. INTRODUCTION

Wind power generation and photovoltaic power generation have an important position in the global renewable energy development strategies due to their relative maturity and abundant resources[1-2]. Governments have introduced various policies to promote the development of wind power generation and photovoltaic power generation technology and the consumption of electricity[3]. However, the wind energy and solar energy in China have the characteristics of high concentration and reverse distribution with the load center. It is necessary to expand the range of renewable energy consumption through long-distance transmission and ultra-high voltage(UHV) technology[4-8]. UHV AC and DC technologies for long-distance transmission are being developed. At present, the State Grid Corporation system has realized that all power grids are connected by AC and DC transmission. In 2016, the operation scale of the UHV system reached “six-crossing and five-straight”, and it is the only power grid in the world that operates both UHV AC and DC. The UHV AC-DC compound system with high percentage renewable energy has already become the typical characteristics of the state grid.

However, with the development of UHV AC/DC hybrid power system, the power control of tie line in UHV AC/DC hybrid power grid is very important.The fluctuation of the power of the tie line may damage the st atic stability of the power grid, cause bus voltage fluctuation, and even endanger the safety and stability of high voltage primary equipment and interconnected power grid.Inaddition, tie-line power control also involves multi-level dispatching mode, as well as grid frequency, intercontinental tie-line exchange power and specific control of stable power flow section[9-12].Therefore, the automatic generation control of UHV AC/DC hybrid power syst em is urgently needed to be studied and solved.

This paper discusses the main problems and shortcomings of the UHV AC-DC compound system with large scale renewable energy based on the development and change of the control strategy of North China power grid's tie-line, and proposes an effective control strategy in combination with the actual situation to provide references for building the UHV AC-DC compound system.

II. HISTORY OF TIE-LINE POWER CONTROL IN NCPG

Before 2011, NCPG consisted of five parts, Jingjintang power grid, Heibei power grid, Shanxi power grid, West Mongolia power grid. The sub grids operated independently. The frequency control was centered on Jingjintang power grid. Flat Frequency Control (FFC) was adopted as the control strategy, i.e., generators of Jingjintang power grid was in charge of frequency control of the regional power grid. Flat Tie line Control (FTC) was adopted for Heibei power grid, Shanxi power grid and West Mongolia power grid. They were responsible for controlling the power exchange with Jingjintang power grid. The configuration of the control strategy is presented in Fig.1.

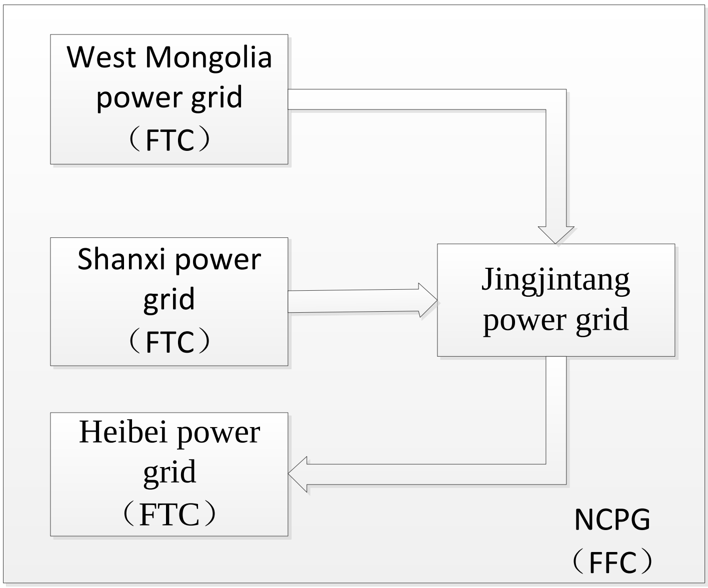

Fig.1 Configuration of NCPG-1

This control strategy wasnot hard to be realized, as the control aim was clear and technological realization was easy. Nevertheless, the generators of provincial power grids would practice continuous adjustment when an accident took place. The continuous adjustment was detrimental to frequency restoration and also increases wearing.

In 2001, NCPG was connected with Northeastern China power grid via AC transmission line. The control strategy could no longer meet the control requirements. Thus, a new strategy was proposed, namely, Tie-line Bias Control (TBC). In TBC, Jingjintang power grid was in charge of frequency regulation of NCPG, and the regulation of tie-line power exchange. The advantages of the proposed control strategy were as follows. Firstly, when there was a power unbalance in Shanxi, West Mongolia or Hebei provincial power grid, the power unbalance would not impact the Area Control Error (ACE) of the rest of the power grids. In another word, only Jingjintang power grid and the responsible provincial power gridswere responsible for the ACE of NCPG.

With this strategy being in place, the continuous adjustment of power output of generators was effectively avoided. In addition, the power unbalance within NCPG would not have any influence on Northeastern China Power Grid, as can be seen from Fig. 2.

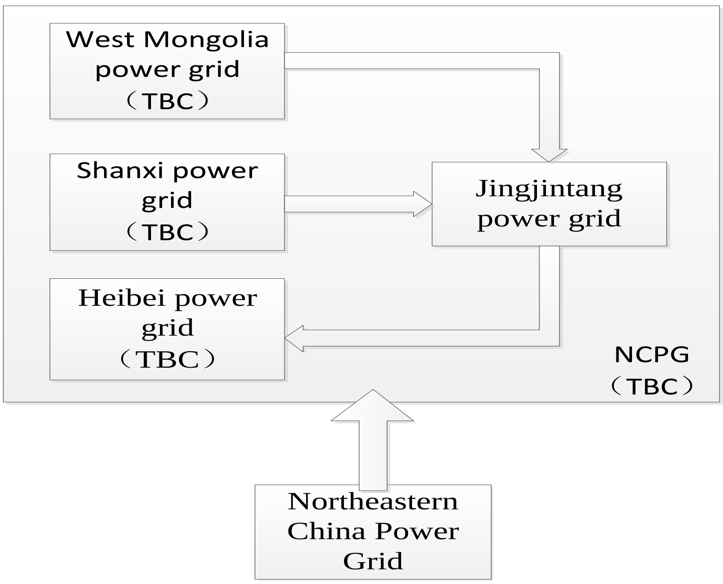

Fig.2 Configuration of NCPG-2

As the development of NCPG stepped up, the load level had been increasing continuously, especially in 2005, when the inclusion of Shandong Power grid led to the decrease of the proportion of Jingjintang power grid in NCPG. In addition, the frequency regulation of was not as good as expected due to the involvement of Shanxi, Shandong, West Mongolia and Heibei provincial power grids in frequency regulation.

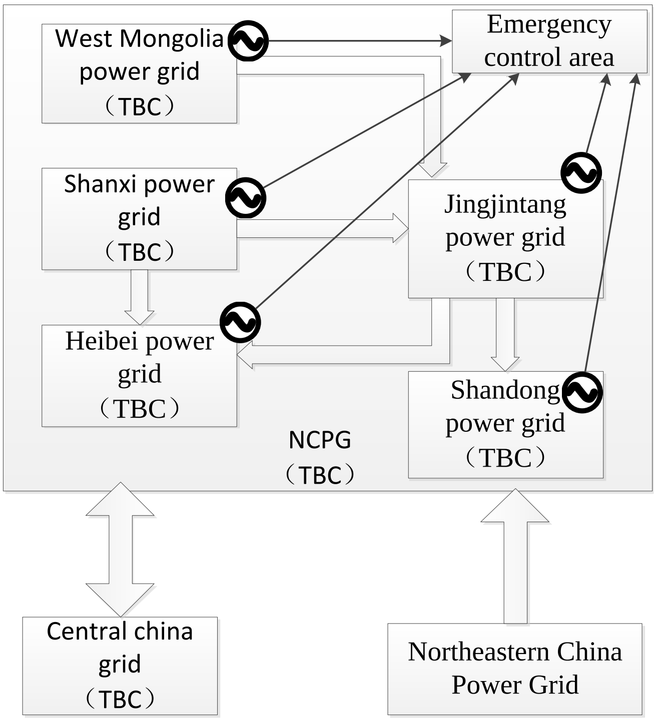

Fig.3 Configuration of NCPG-3

In late 2008, the 1000kV HVAC transmission line, which connected Changzhi and Jinmen via Nanyang, was put into service. Since the power fluctuation of the transmission line led to tremendous voltage variation in nearby substations, a new control strategy was proposed.

The aim of the control strategy was to reduce the power unbalance to an acceptable level. Therefore, the following changes were made. ① Establish a new control area, namely, Jingjintang control area. TBC was adopted for this control area. Thus, Jingjintang control area was only responsible for its own power balance, reducing the regulation workload. ①Three protection lines were established. The first protection line was aimed at unifying the control mode of all control areas. This method could meet the requirement of ACE and the tie-line power deviation of HVAC. The principle of this method could be elaborated as follows. The ACE of all control area was added with an extra value, which encouraged the generators to regulate the power output, so as to reduce the power deviation of the inter-area tie-line power. The second protection line referred to the high voltage emergency control area, which comprised of generators with excellent regulating performance. The third protection layer would be in place when the tie-line power exhibited substantial fluctuations. When this control mode was activated, the AGC meeting certain criterion would be suspended, so as to avoid further detrimental implications. In practical operation, the first layer protection had the highest priority, followed by the second and third layer protection. Operational experience suggested that the new control strategies not only effectively alleviated the regulating pressure of generators in Jingjintang control area, but also shared the responsibility among control areas in an appropriate way. The configuration of the proposed method is shown in Fig.3.

III. OPERATIONAL FACTS AND CHALLENGES OF NCPG

3.1 Present operational facts

By 2017, the 1000kV HVAC power grid is characterized by two horizontal and one vertical lines, 500kV HVAC eight horizontal and three vertical lines. These power transmission channels are responsible for delivering the electrical power from West to East, form North to South. The inter-area tie lines consist of one HVAC and five HVDC lines. NCPG connects with Middle China Power Grid via 1000kV Changnan line, Northeastern Power Grid via Lugu HVDC and Gaoling back-to-back station, Northwestern Power Grid via Yindong HVDC, Eastern Power Grid via Yanhuai and Xitai HVDC. Generally speaking, NCPG plays the role of both sending end and receiving end.

As for the provincial power grids of NCPG, great changes have been witnessed in recent years.

As more HVDC lines have been commissioned, the corresponding power plants are listed as Jingjintang generators. The electrical power generated by these generators is distributed via the tie lines among the provinces. This shifts the status of Jingjintang power grid from conventional power receiving end to power transfer hub. This type of power grid is characterized by multi-direction, multi-channel and multi-point power flow. The operational difficulty of this type of power grid is large.

Heibei power grid has become an important power transfer hub, which connects Shanxi, Jingjintang and Shandong power grids. The penetration power flow within the power grid is very heavy, as the power transfer channels which deliver electrical power from north to south (or form west to east) all pass through it. In addition, in summer periods, the air conditioner loads are increasing substantially in Heibei province. Therefore, the power shortage is expected to see further increase in 2018, as compared with 2017.

Shanxi power grid is one of the power suppliers in NCPG. As the delivered power via Yanhuai HVDC rises, the nine 500kV tie lines and 1000kV HVAC line might face operational risks brought about by the power unbalance of YanhuaiHVDC , if a severe HVDC fault occurred.

As a receiving end, the number of AC tie lines of Shandong province has increased from 4 to 8. Therefore, its connection with main NCPG is stronger than before. However, this is too little to match the expected load increase. It is expected that there would still be power shortage in the summer time of 2018. As for HVDC, the terminals of Yindong and Lugu HVDC are geographically near to each other. Hence, the fault of AC power grid may induce commutation failure of nearby HVDC lines. The resultant power unbalance would finally lead to the disintegration of the whole power grid.

The configuration of West Mongolia power grid did not change substantially in recent years. It connects with major NCPG via four 500kV transmission lines. Since the electrical distance is long and the power system often operates around the stability boundaries, West Mongolia power grid may operate beyond its stability limitations in the wake of large power unbalance in NCPG.

Due to the uneven distribution of primary energy sources, thermal plants with low regulating ability accounts for 70% of the total installed capacity (0.35 billion kilowatt). Hydro plants with high regulating ability have a share of less than 7%, indicating insufficient capability of peak load regulation. As renewable sources increase rapidly, the total installed capacity of 2017 is seven times as much as that of 2010. The penetration level of NCPG in 2017 has reached 32%, 10% larger than the average penetration level of China. However, the overlapping of windy periods and heating season aggravates the unpredictability further, thus posing great challenge to the safety and stability of power systems. Moreover, as power market gains momentum, how to fully take advantage of the peak load regulation capability of power systems without breaking the stability of power systems, so as to accept as much renewable power as possible has become a problem that is yet to be solved.

3.2. Upcoming challenges

The following conclusions can be summarized by examining the aforementioned operational facts of NCPG. As the expansion of high voltage power grid and renewable power sources gain momentum, NCPG has witnessed tremendous change in structure of both power sources and power grid. This also brings about far-reaching influence on the characteristics of power systems. The subsequent problems and challenges related to power dispatching can be summarized as follows.

1) Power flow is unevenly distributed. The proportion of penetration power has been on an up trend. Overloading is serious in certain channels. Scheduled inter-provincial tie-line power, power generation conditions of near-line generators, play an important role in affecting the level of penetration power flow. Hence, the problem of overloading can be effectively alleviated if these two aspects are taken into consideration.

2) The large-scale grid integration of HVDC into NCPG poses enormous challenge to the safety and stability of power systems. NCPG is characterized by being both big sending end and receiving end. DC faults that occur in NCPG can induce substantial power unbalance within the power grid. If TBC were adopted as the control strategy for frequency regulation, the provincial power grids would not be able to provide immediate power support to assist frequency restoration, as DC power flow has a large implication on the power balance of provincial power grids. Furthermore, DC faults may enlarge the fault impact area by making the power system operate beyond cross-section stability limitations, especially in the case of Shanxi and Inner Mongolia power flow cross section, where the cross-section power flow is stressed to operational limit.

3) In summer periods, some of the provincial power grids suffer from great power shortage. In 2017, the maximum daily loads of provincial power grids nearly took place simultaneously, which made it very difficult to realize effective mutual power support by modifying scheduled daily tie-line power.

4) Accepting renewable power is increasingly difficult due to inappropriate structure of power sources, overlapping of heating season and windy periods, and diminishing peak load regulation resources caused by expanded installed capacity of solar power. In some provincial power grids, the most difficult time for peak load

regulation has been shifted from late-night valley to mid-day peak.

IV. NOVEL APPROACHES

The proposed methods to deal with these problems can be elaborated as follows.

1) Calculate the stability boundaries by on-line safety analysis software before implementing closed-loop automatic generation control (AGC) based on the computational results.

As required by the operational codes of NCPG, the stability boundaries are currently computed under the condition that the power system operates in extreme manner. On-line stability analysis can give the stability boundaries of power systems. Closed-loop AGC is then realized by adjusting the power output of generators according to the calculated stability boundaries, power flow sensitivity, loading condition of power flow cross sections. This method can help control the power flow of important power flow cross sections, so as to achieve accurate and efficient regulation of power systems and ensure its safe and stable operation.

2) Introduce dynamic ACE in NCPG

Compared with conventional ACE control, dynamic ACE enables all the provincial power grids to take the responsibility of frequency restoration in the wake of large disturbances, when sudden power loss from outside of the area takes place. In another word, the software will distribute the back-up capacity among the provincial power grids according to their back-up amount, when short-period power variation or frequency variation rate of NCPG exceeds the threshold. The shared ACE of provincial power grids will be added to the original ACEto get the dynamic ACE. With this approach in place, the frequency of NCPG can be resumed to normalitypromptly.

3) Combine Jingjintang and Shandong control area in the presence of power shortage

In an interconnected power grid, when a sub grid experiences power shortage, other sub grids can provide power support. This practice is named power sharing. After the commissioning of three HVAC lines in NCPG, the connection among provincial power grids became stronger than before, since the number of connection channels increased. This also increases the practicability of power sharing. There are two methods in terms of power sharing.

①Cancel Jiangjintang, Heibei and Shandong control area, and setting the power output of generators in Heibei and Shandong control areas to the maximum. Then, Calculate the ACE by assuming Jingjintang and shandong control area as a whole (Jingjinjilu control area). The generators which belong to Jingjintang control area are responsible for ACE control.

② Establish Jingjinjilu control area (the combination of Jingjintang and Shandong Control area) and distribute the ACE to sub grids based on B (Frequency bias). Both methods can realize power sharing. The first method ensures that all standby capacity is controlled by NCPG regulators, and the power unbalance is solely taken by the generators of Jingjintang control area. When this method is applied, ACE control may become difficult, and the power adjustment of generators may become overactive. As for the second method, ACE is controlled by the generators of Jingjintang, Heibei and Shandong control area. The effectivenessof this method is better than the first method. However, some power grids may preserve unnecessary back-up capacity and refuse to transfer the back-up to other power grids which are in desperate need of help. In a word, the two methods can both alleviate the power balancing problem of Jingjintang, Heibei and Shandong power grid, even though there is still some space for optimization in the practical case.

4) Establish ancillary power market

Along with the development of power market, NCPG is currently at the stage of transition from plan-based mode to market-based mode. It is expected that power market can play a more important role in power system operation. By setting up a mature ancillary power market, the capability of power systems to accept renewable power can be substantially enhanced. Furthermore, the power system will operate more efficiently with the assistance of power market.

Ancillary market of peak load regulation.The mechanism of the market canbeexpounded as follows. Generators are prioritized by their ability of frequency regulation. Thosewithexcellentperformanceof frequency regulation aregranted high priority in frequency regulation, and will be compensated economically. The compensation price is initially declared by power suppliers and finally determined by market clearing price. The compensation amount is sharedamong the participating generators according to the measured electricitygeneration. The expected effect is to encourage the generators with good performance of frequency regulation to make more contributions, so as to enhance the capability of secondary frequency regulation of power systems.

Ancillary market of peak load regulation.The mechanism of the market canbeexpounded as follows. The peak load regulation resources are provided by power suppliers via price competition, before being used by the power grid according to the bidding price. The practice of frequency regulation is executed through modifying the scheduled tie-line power among provincial power grids. The aim is to encourage the power suppliers to participate in peak load regulation in a more positive way. In addition, the market can also help distribute frequency regulation resources efficiently, so as to promote the acceptance of renewable energy.

V. CONCLUSIONS

The following facts can be concludedaccording to the analysis above.

1) Important power cross sections and transmission lines are overloaded. Some provincial power grids suffer form power shortage in summer periods. The grid-integration of HVDC brings about operational risk to the power grid. The pressure of accepting renewable energy sources has been increasing.

2) There is an urgent need to improve the control strategy of tie-line power.

To resolve these problems, the following works have been done. The paper proposes a new control strategy of frequency regulation, which involvesclosed-loop control of automatic generation, dynamic ACE, combination of Jingjintang and Shandong control area (Jingjinjilu control area), and establishmentofancillarypower market. The proposed approach is also related to the control strategy of tie-line power. Therefore, the proposed control strategy of frequency regulation is actually executed by changing the control schemes of tie-line power. Furthermore, the control schemes of tie-line power needs to be in line with the operational codes of the power grid, so as to ensure the safety and stability of the power system.

REFERENCES

[1]. Bevrani, H., Ghosh, A. and Ledwich, G., 2010. Renewable energy sources and frequency regulation: survey and new perspectives. IET Renewable Power Generation, 4(5), pp.438-457.

[2]. Weitemeyer, S., Kleinhans, D., Vogt, T. and Agert, C., 2015. Integration of Renewable Energy Sources in future power systems: The role of storage. Renewable Energy, 75, pp.14-20.

[3]. Hammons T J, Lescale V F, Uecker K, et al. State of the art in ultrahigh-voltage transmission. Proceedings of the IEEE, 2012, 100(2): 360–390

[4]. Purvins A, Zubaryeva A, Llorente M, et al. Challenges and options for a large wind power uptake by the European electricity system. Applied Energy, 2011, 88(5): 1461–1469

[5]. Giebel G. A variance analysis of the capacity displaced by wind energy in Europe. Wind Energy (Chichester, England), 2007, 10 (1): 69–79

[6]. Sun, Y., Ma, X., Xu, J., Bao, Y. and Liao, S., 2017. Efficient utilization of wind power: Long-distance transmission or local consumption?. Frontiers of Mechanical Engineering, 12(3), pp.440-455.

[7]. Liu Zhenya．Innovation of UHVAC transmission technology in China[J]．Power System Technology，2013，37(3)：566-574(in Chinese)．

[8]. Liu Zhenya，Qin Xiaohui，Zhao Liang，et al．Study on the application of UHVDC hierarchical connection mode to multi-infeed HVDC system[J]．Proceedings of the CSEE．2013，33(10)：1-7(in Chinese)．

[9]. Moawwad, A., El-Saadany, E. and El Moursi, M.S., 2017. Dynamic Security-Constrained Automatic Generation Control (AGC) of Integrated AC/DC Power Networks. IEEE Transactions on Power Systems.

[10]. Bevrani, H. and Hiyama, T., 2016. Intelligent automatic generation control.CRC press.

[11]. Rakhshani, E., Remon, D., Cantarellas, A.M. and Rodriguez, P., 2016. Analysis of derivative control based virtual inertia in multi-area high-voltage direct current interconnected power systems. IET Generation, Transmission & Distribution, 10(6), pp.1458-1469.

Jian LIU was born in 1979. He obtained his master degree in Tsinghua University, Beijing, China, in 2006. He is currently working in the North Subsection of State Grid Corporation of China. His research interests include power system stability and power grid dispatching. Email: liu.jian@nc.sgcc.com.cn

Lei Guo was born in 1984. He obtained his Ph. D in Electrical Engineering from Zhejiang University, in 2012. He is currently working in the North Subsection of State Grid Corporation of China. His research interests include power system stability, power grid planning, intelligent information processing technlogy in power system. Email: guo.lei@nc.sgcc.com.cn

Jian.LIU "Investigation On Tie-Line Power Control Strategy Of HVAC-HVDC Hybrid Power System Of Northern China "The International Journal of Engineering and Science (IJES),), 7.9 (2018): 10-15