Institutional and pricing reforms for pumped storage hydr**oelectricity** in China: supporting the energy transition.

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Abstract:

As part of its energy transition strategy, China has set ambitious targets for increasing the contribution of renewable energy and, in particular, of wind power. However, the Chinese power sector has not undergone the necessary reforms to facilitate the integration and absorption of a larger share of variable renewable energy. This is evident from the difficulties in absorbing wind power from already commissioned wind farms and the resultant curtailment of wind power. Pumped storage hydroelectricity (PSH) is a flexible power source that can facilitate higher penetration levels of wind power as well as complement China's growing nuclear power capacity. However, regulatory policy constraints have restricted the effective utilization of existing PSH capacity and discouraged investment in new PSH capacity. This paper examines these constraints and assesses the likely impact of new policies designed to address them. Finally, policy recommendations and concluding remarks are provided. This paper contributes to the literature on renewable energy integration from a new perspective. The lessons from China are relevant to other countries going through the energy transition.

Keywords: Pumped storage hydroelectricity; institutional constraints; renewable energy integration; energy transition; China

Highlights:

Highlights the role of pumped storage hydroelectricity in renewable energy integration;
Examines the development of pumped storage hydroelectricity in China;
Reviews the regulatory policies on pumped storage hydroelectricity in China;
Analyzes the operation and pricing regime for pumped storage hydroelectricity in China;
Makes policy recommendations for promoting pumped storage hydroelectricity in China.

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1. Introduction

As part of its energy transition strategy, China is vigorously promoting the development of renewable and nuclear energy. It has emerged as the leading wind power producer in the world with 114.8 GW of cumulative installed capacity by the end of 2014, accounting for 31.1% of the world total [1]. However, this capacity has not been well translated into electricity generation. Wind curtailment[2] has increased since 2009, particularly in the Three Northern China Regions (Northeast, North and Northwest China). The curtailment of wind generation was 16.2 TWh across the country in 2013 [2].

Increasing levels of wind power penetration in the Chinese power system has created several technical constraints to the reliable operation of the grid and to the dispatch of other power plants. In addition to requiring sufficient transmission capacity to transmit electricity generated by wind farms located thousands of kilometers from load centers, wind power also requires an adequate level of flexibility in the power system to offset the inherent variability of wind power. The spinning reserve and frequency regulation capacity of the power system also need to be increased with the growing penetration of wind power.

China also has ambitious plans for nuclear energy. The installed capacity at the end of 2014 was 20.11 GW. After a pause in construction following the Fukushima disaster, the government is pressing ahead with the aim of having 58 GW installed by 2020 [3]. This capacity will provide valuable base load supply, especially in the coastal provinces which have few reserves of fossils fuels, but may be under-utilized at times of low demand.

Pumped storage hydroelectricity (PSH) offers a technically and economically feasible solution to the problem of the variability of wind energy, as has been demonstrated in other countries (see details in Section 2). It also offers an opportunity for nuclear power

[2] Curtailment refers to temporary disconnection of wind farm farms or non-acceptance of the electricity that could be generated by wind farm farms due to excess generation capacity in the system, transmission bottlenecks and grid stability issues.

stations to dispatch their energy during periods of low demand as well as providing peak load supply in regions where power generation is dominated by coal. Despite this growing long-term need, China's PSH capacity has expanded slowly and reached only 21.54 GW by the end of 2013, a mere 1.76% of the nation's aggregate generating capacity, and the average annual generating hours per plant barely exceeded 1,400 hours [4]. In recognition of this deficiency, China's government has set targets for PSH capacity of 30 GW by 2015 and 70 GW by 2020, accounting for 3%-5% of the total installed generation capacities in the country [5]. However, these goals fall far short of the estimated potential capacity of 130 GW within the territory of the State Grid Corporation [6].

Along with challenges arising from the integration of variable renewable energy in the recent decades, there is a common understanding that a high degree of flexibility is required of the grid. While a number of studies have examined the role of PHS in addressing these challenges [7-10], others have looked into the constraints on PSH development [11-14]. Yang and Jackson [11] identified that the main limiting factors for PSH in the United States appeared to be environmental concerns and financial uncertainties rather than the availability of technically feasible sites. Steffen's study [12] showed that in Germany the most obvious constraints on PSH were that restrictions on the size of reservoirs prevent them from adequately supporting excessive renewable generation over very long periods of time. In addition, PSH plants are seen to have a detrimental impact of the landscape. Kraiačić [13] argued that in Croatia not all services that PSH provides to the electricity system were adequately rewarded by the electricity market, and that other elements, outside the market, were likely to influence the operation of PSH, such as the regulated level of curtailment of excess renewable energy. Sivakumar [14] revealed that the major constraint for PSH operation in India was the deficit of off-peak power available for pumping in all the regional grids except the north-east region.

In contrast, in China, recent accounts have identified the lack of flexible power supply as one of the major causes of wind power curtailment. Zhao et al. (2012)[15] argued that the dominance of coal in the fuel mix of power plants in the Northeast China Grid had restricted wind power generation during the winter heating periods in recent years. Wang et al. (2012) [16] suggested that power supplies which can be dispatched more flexibly or provide much-needed energy storage should be priced and incentivized accordingly. Finally, Yu et al. (2011) [17] identified that pumped hydro storage provided an effective way to accommodate wind power integration.

However, to the best of our knowledge, few English language accounts have looked into the underlying reasons for the lack of flexible power sources in China such as pumped storage hydroelectricity. Exceptions include Zeng's studies [18-19], which provide overviews of the development status of PSH and related policies in China. Though some Chinese language literature does study the operational model and tariff regime for PSH in China, most analyses fail to examine these issues comprehensively from the institutional and regulatory perspectives, let alone examine the most recent national regulations and policies governing PSH [20-24].

Building on the existing literature, the aim of this paper is to identify the institutional and regulatory constraints of PSH in China through a comprehensive examination of evolution of PSH development and policies in China and to assess the likely efficacy of the new regulations. This work could provide an understanding of the reasons for the slow growth of PSH in China over the last twenty years, and to make policy recommendations as well. The paper starts with a brief account of the role of PSH in a power system. Then it examines how PSH developed in China under a monopolist power sector between 1968 and 2002, and describes the unfavorable operating and pricing regimes. The subsequent section looks at the period 2003 to 2014 and shows how the level of investment in PSH remained too low despite policy changes. Section 5 summarizes the recent policy initiatives announced in 2014 and Section 6 assesses the adequacy of these measures and recommends further actions in order to provide sufficient support to the development and use of PSH in China. Section 7 provides concluding remarks and emphasizes the relevance of the analysis for other countries.

2. The role of PSH

PSH, the most flexible power source for peak regulation, is used to store and manage energy or electricity and represents almost 99% of current worldwide electricity storage capacity [25]. As shown in Fig.1, the principle of a PSH project is: (1) the PSH plant stores electricity by moving water from a lower to an upper reservoir. Electrical energy is converted to potential energy and stored in the form of water at an upper elevation. Pumping the water uphill for temporary storage 'recharges the battery' and, during periods of high electricity demand, the stored water is released back through the turbines and converted back to electricity like a conventional hydroelectricity plant. The efficiency of a PSH system is typically 70%-80%, which means the energy generated is usually 70%- 80% of the energy used in water pumping. This energy loss makes the PSH plant a net consumer of energy [26]. The advantage of a PSH plant comes from the fact that once the facility is operational, it can quickly respond to energy demands. In this way PSH plants can provide peak shaving and valley-filling, spinning reserve capacity, phase modification and frequency control.

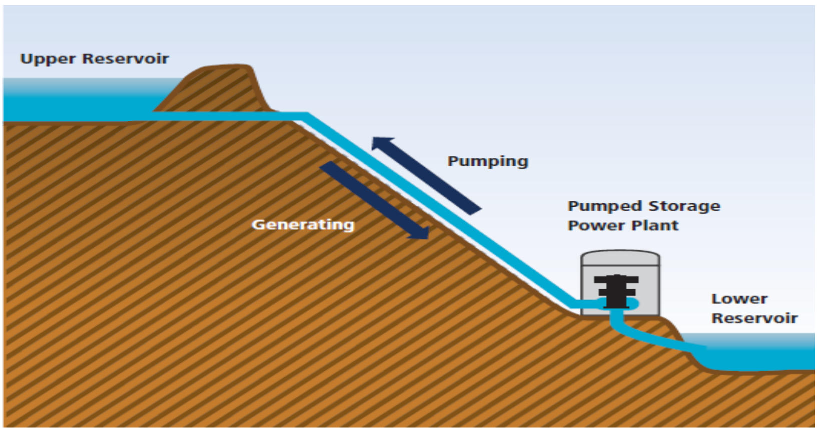

Fig.1. Principle of pumped storage hydroelectricity plants
Source: [26]

The use of PSH started as early as 1890 in Italy and Switzerland. More generally, the majority of plants were built from 1960s to the late 1980s. This was due, in part, to the rush to nuclear energy after the oil crises in the early 1970s. For instance, PSH development in the United States and European countries was closely correlated to the growth of nuclear power. PSH was used as a system tool to supply energy at times of high load demand and to allow nuclear units to operate in their base load mode during low load demand periods. However, in countries with rich hydro energy and no nuclear power, PSH was developed primarily to enhance the operation and efficiency of large scale hydro power plants [27].

In the USA, Japan and the EU, the installed capacity of PSH reached 2.14%, 8.70% and 3.35% of their total installed capacity in 2010 respectively, even though gas-fired units (another flexible source for peak and frequency regulation) accounted for 23.38%, 27.42% and 23.47% of total installed capacity respectively [28]. In contrast, notwithstanding that the share of gas-fired units available in China is rather low, the share of PSH installed capacity in the country is only 1.76% [28]. According to China's 12th Five-Year Plan for Energy Development (2011-2015), only if the share of PSH installed capacity reaches 2.01% by 2015, could the national grid possibly have sufficient flexibility to effectively mitigate the impact on the grid of the integration of renewable energy such as wind power [29]. The 12th Five-Year Plan for Renewable Energy Development states that the installed capacity of PSH must reach 70 GW by 2020 for it to play its role in accommodating large scale renewable energy, peak shaving and valley filling as well as ensuring the security and stability of the grid operation [5].

3. PSH under monopoly regime: 1968 to 2002

3.1. PSH development

Before 2002, China's power sector was dominated by a vertically-integrated monopoly. From 1949 to 1997, this took the form of the Ministry of Electrical Power (and predecessors with other names). In 1997, the government created the State Power Corporation of China which took over all the assets of the Ministry which itself was abolished the following year. Despite the presence of a national monopoly, a significant proportion of generating capacity and some distribution networks had been constructed by local government entities, independent from the state monopoly [30]. These local enterprises also played a key role in the construction of PSH plants.

The first PSH plant in China was completed at Gangnan in Hebei Province in 1968 with an installed capacity of 11 MW. In 1973, two other PSH plants were built at Miyun in Bejing Municipality with a total installed capacity of 22 MW [18]. In the late 1980s, along with the country's dramatic economic development, the electrical power system expanded rapidly with total generating capacity rising from 390 GW in 1985 to 590 GW in 1990 [18]. The grids that were dominated by thermal power, such as the Guangdong, North China and East China grids, faced major peak regulation problems due to the lack of economic means of peak supply such as hydroelectricity. As a result, these regions began to build more PSH plants. Other grids dominated by hydroelectricity also started to construct PSH plants for the purpose of meeting the requirements of economic operation and power source restructuring.

In the 1990s, PSH plants developed more rapidly. In 1991, the Panjiakou Plant with 270 MW installed capacity was commissioned. This was followed by other large PSH plants including the Guangzhou Plant with 2,400 MW installed capacity, the Shisanling Plant in Beijing with 800 MW installed capacity, and the Tianhuangping Plant with 1,800

MW [20] (See Table 1).

This growth of PSH capacity was largely uncoordinated and driven by local governments wanting peak-load capacity in regions dominated by coal-fired generation. Most plants were jointly invested by local governments in partnership with the local grid subsidiary of the national power company or ministry. Ownership of such plants lay with the grid company. This locally-led development of PSH led to a variety of approaches to structuring the operating and pricing regimes for PSH plants and a number of different schemes arose. The most common of these were the unified operation scheme that applied to plants wholly-owned by the state monopolist, and the independent operating regime that applied to other plants and under which three models can be identified

Table 1 PSH plants in China at the end of 2013

Region	Plant (Commissioned year)	Unit×capacity /unit (MW)	Commissioned capacity (MW)	Capacity under or to be constructed (MW)
Total			21545	14240
North China	Hebei Fengning	6×300		1800
	Beijing Shisanling (1997)	4×200	800	
	Hebei Panjiakou (1992)	3×90	270	
	Shandong Taian (2006)	4×250	1000	
	Hebei Zhanghewan (2009)	4×250	1000	
	Shanxi Xilongchi (2008)	4×300	1200	
	Beijing Miyun (1973)		22	
	Hebei Gangnan (1968)		11	
	Huhehaote	4×300		1200
East China	Anhui Jixi	6×300		1800
	Zhejiang Xianju(2013)	4×3750		1500
	Fujian Xianyou	4×300	1200	
	Anhui Fouziling	2×80	160	
	Zhejiang Tianhuangping	6×300	1800	
	Zhejiang Tongbai (2006)	4×300	1200	
	Anhui Xianghongdian	2×40	80	
	Jiangsu Yixing (2008)	4×250	1000	
	Anhui Langyashan (2007)	4×150	600	
	Anhui Xiangshuidian	4×250	1000	
	Jiangsu Puyang	6×250		1500
	Jiangsu Shahe (2002)	2×40	100	
	Zhejiang Xikou (1998)	2×40	80	
Central China	Jiangxi Hongping	4×300		1200
	Henan Huilong (2005)	2×60	120	
	Hunan Heimifeng (2010)	4×300	1200	
	Henan Baoquan (2011)	4×300	1200	
	Hubei Bailianhe (2009)	4×300	1200	
	Hubei Tiantang (2002)		70	
	Sichuan Cuntangkou		2	
Northeast China	Jilin Dunhua	4×350		1400
	Heilongjiang Huanggou	4×300		1200
	Jilin Baishan (2008)	2×150	300	
	Liaoning Pushihe (2011)	4×300	1200	
Tibet	Tibet Yangzhuoyong		90	
Southern Grid region	Guangdong Guangzhou (Phase I: 1997; Phase II:		2400	
	Guangdong Huizhou		2400	
	Guangdong Qingyuan			1280
	Shenzheng			1200

Source: [20] and the websites of relevant PSH plants.

3.2. The unified operation regime: Shisanling model

In this regime, the PSH plant is wholly owned by the grid company rather than being an independent legal entity. This operation regime is applied to most of the PSH plants built before 2004. The Shisanling Plant in Beijing is a typical example of this regime.

The Shisanling Plant has been directly under the North China Grid Company since its commissioning in 1995. Its financial performance is appraised by key indexes including material cost, overhaul and maintenance cost, and management cost, among others. Generation output used to be in the appraisal indexes but was removed due to the recognition that the main function of a PSH plant is to provide regular peaking, frequency control and emergency standby services and that its generation output is generally very small at around 500 hours per year. The advantage of the unified operation regime was that it avoided conflicts of interest between the grid company and the PSH plant, and thus it supported grid security and stability.

Plants owned by the grid were paid according to generation-based tariff. Under this tariff model, the PSH plant receives payment for each megawatt generated in response to the dispatch instructions of the system operator. Since the plant output depends on the dispatch scheme, its revenue cannot be guaranteed. Further, the PSH plant receives no compensation for the services it supplies such as peak regulation, frequency control and spinning reserve. In this way, the generation-based tariff regime is the same as that for ordinary power plants. The majority of the PSH plants built in China prior to 2004 adopted this tariff regime, including the Shisanling Plant, the feed-in-tariff (FIT) of which is RMB 0.80/kWh [22].

3.3. The independent operation regime

In this regime, the PSH plant is a legal entity and there are three operation models:

the self-operation, commission and negotiated lease models.

3.3.1. The self-operation model: Xianghongdian model

In this model, the owner operates the plant. In other words, the PSH owner and operator are the same entity. The plant obtains its revenue by providing power, capacity and/or other services to the grid company at a government-approved FIT under the generation-tariff regime and pays the government-approved tariff to the grid company for water pumping. As such, the plant is exposed to changes in government tariff policy.

The Xianghongdian Plant in Anhui Province is an example. In 2000, the government-approved FIT for this plant was RMB 1.00/kWh and the tariff for water pumping was RMB 0.214/kWh. In 2002, however, the FIT for the plant generation was reduced to RMB 0.85/kWh while the tariff for water pumping remained constant. In 2003, due to the increase of water pumping cost, the government changed the tariff for the excess output (the part exceeding the approved output) to RMB 0.37/kWh. As a consequence, the plant suffered financial losses until 2004 when the tariff for generation was fixed and the permitted annual output was raised from 105.26 GWh to 130 GWh [22].

3.3.2. The commission model: Tianhuangping model

In this model, ownership is separated from operation. The operation of the PSH plant is assigned to the grid company. A small number of plants operate under this model. A typical example is the Tianhuangping Plant in Zhejiang Province. In 1998, Tianhuangping Pumped Storage Hydroelectricity Co. Ltd., the owner of the plant, entered into a commission agreement with the East China Grid Company (the ECGC), entrusting the ECGC with the daily operation of the PSH plant including production safety, electricity tariff scheme, equipment overhaul and maintenance, and purchase of spare parts. The output of the plant is dispatched by the ECGC and distributed to the three provinces and one municipality within the jurisdiction of the ECGC.

The two-part tariff regime, which has been applied to this plant ever since 2000, consists of a capacity tariff and a generation tariff (FIT). The capacity tariff (also called commission fee) paid to the PSH plant was set through negotiation between the plant and the ECGC. The Plant receives a capacity tariff of RMB 470/kW per year and a FIT of RMB 0.7915/kWh while paying RMB 0.3453/kWh to the grid company for pumping water [18].

3.3.3. The negotiated lease model: Guangzhou model

In this model, the ownership and the operation of the plant are also separated. The negotiated lease, as the name implies, means that the lease price, namely the capacity tariff, of the plant is negotiated between the grid company and the PSH plant. Under this tariff regime, the PSH plant receives payment based on its capacity. This model has two main advantages. Firstly, the PSH plant can obtain stable revenue provided the lease price is reasonable. Secondly, the grid company is able to unify power dispatch so as to fully utilize the PSH plant in peak regulation, load follow and reserve services. However, it also has distinct disadvantages: once the lease price is determined, the plant loses the opportunity of earning more revenue through market competition, and since the lease price is integrated into its operating cost, the grid company is exposed to operational risks.

This lease model was used only before 2003, and the prime example is the Guangzhou PSH plant, currently China’s biggest PSH plant with a total installed capacity of 2400 MW. The plant was invested and constructed jointly by the Guangdong Electric Power Group (54% share), the National Development and Investment Company (23% share) and the Guangdong Nuclear Power Investment Company (23% share). The Guangdong Pumped Storage Joint Operation Company was set up as an independent legal entity to operate the plant [23] and all the units in the plant had been put into operation by 2000.

In May 1995, the plant adopted the lease model for the 50% installed capacity of its Phase I (1200 MW) and the tariff followed the single capacity-based approach. The Guangdong Grid Company and the Guangdong Nuclear Power Group jointly leased the 1200 MW capacity PSH plant. The negotiated lease price of RMB 280/kW per year is based on the yearly operation cost, capital and interest cost, taxes and profit and is equally shared by the two lessees. While the capacity is dispatched by the Guangdong Grid Company, the Guangdong Nuclear Power Group is ensured of its stable and secure operation without any commitment to peak regulation. The economic interests of the Guangzhou PSH Plant are met by following system operator's instructions. This model turned out to be successful and was later applied to the other four 300 MW units in Phase II [23].

The Guangzhou model appears to have achieved a "triple win" outcome beneficial to all contracting parties: the PSH plant owner shares no operational risks; for the grid company, the plant works like its workshop that could be dispatched to provide peak regulation, valley filling, frequency control and other auxiliary services to ensure the safe and stable operation of the grid; and nuclear power plants can achieve more hours of generation .

3.4. Summary

The construction of PSH plants during the 1990s remained at a relatively low level and the installed capacity reached only 5.6 GW in 2000 [26]. Most of these plants were constructed under the unified operation regime with a generation-based tariff which was unattractive to investors. This tariff regime did not fully reflect the value of the PSH plant and, as a result, the costs of the PSH plants could not be fully compensated. Currently, the Shisanling and Xianghongdian Plants, both affiliated to Xinyuan Company of the State Grid Company (which accounts for the majority of PSH market), have achieved break even , while the Huilong Plant has suffered a cumulative financial loss of RMB 224 million, which is more than two times its investment capital, and is in the state of serious insolvency [33].

Compared to the alternative operating regimes, the self-operation model carried a high risk for the PSH plant with a low probability of being dispatched and a simple but unprofitable generation tariff. Both the negotiated lease (capacity-based) and the commission models with the two-part tariff both carry higher risks for the investor than the simpler model, but can be more financially attractive, depending on the exact terms of the contract. On the other hand, in terms of the availability of the PSH for dispatch, the unified operation model is obviously the best (see Tables 2-4).

Table 2 Comparison of the four models under the two PSH operation regimes in China

PSH operation regime	Operation risks for the PSH plant	Availability of the PSH to be dispatched
Unified operation model	Little	Easy
Lease model	↓	↑
Commission model	↓	↑
Self-operation model	Great	Hard

Table 3 Comparison of the four PSH tariff regimes in China

	Generation-based tariff regime	Capacity-based tariff regime	Generation- and capacity-based two-part tariff regime
Payment basis	Energy generated (i.e. per kWh)	Installed capacity (i.e. per kW)	Energy generated & installed capacity
Value reflected	Generation value	Capacity value	Capacity value and generation value
Revenue Certainty	Revenues depend on the utilization of PSH plant by the grid company.	Revenues are guaranteed by the grid company	Revenues are ensured by the grid company and additional payment depending on utilization.
Assessment	Simple, but not attractive to investors	Tariff sharing policy is crucial	Attractive to investors

Table 4 Application of some PSH tariff regimes in China's PSH plants

Plant	Tariff regime	Tariff
Tianhuangping Plant	Two-part	RMB 470/kW·year for capacity (tax excluded) FIT: RMB 0.7915/kWh (tax excluded) Tariff for water pumping: RMB 0.3453/kWh (tax excluded)
Xianghongdian Plant	Generation-based	FIT: RMB 0.85/kWh; Tariff for water pumping: RMB 0.214/kWh
Huilong Plant	Generation-based	FIT: RMB 0.65/kWh (tax included) Tariff for pumping water: RMB 0.213/kWh
Shisanling Plant	Generation-based	FIT: RMB 0.80/kWh No tariff for water pumping
Panjiakou Plant	Capacity-based	RMB 80 million/year (tax excluded)
Baishan Plant	Capacity-based	RMB 90 million/year
Taishan Plant	Capacity-based	RMB 450 million/year
Tongbai Plant	Capacity-based	RMB 484 million/year
Yixing Plant	Capacity-based	RMB 561.36 million/year
Langyashan Plant	Capacity-based	RMB 267.71 million/year
Zhanghewan Plant	Capacity-based	RMB 490.63 million/year
Xilongchi Plant	Capacity-based	RMB 531.67 million/year
Baoquan Plant	Capacity-based	RMB 507.46 million/year

* Except those noted, all the other tariffs shown in the table are tax-included. All plant names are in their short forms.
Source: [19]

4. PSH under unbundled regime: 2003-2014

4.1. PSH development

In 2002 the government carried out a radical restructuring of the electrical power industry. The main component of this reform was the abolition of the State Power Corporation of China, and its unbundling into two regional transmission and distribution companies and five large generating companies. At least 50% of the generating capacity remained in the hands of enterprises and joint stock companies at local level. Although this reform did not introduce price competition in the strict sense, as tariffs continued to be set by government, there was competition between generators for market share. By chance, this radical structural reform was followed by a period of exceptionally rapid economic growth and soaring energy demand which saw installed generating capacity triple from 400 GW in 2003 to 1,247 GW in 2013 [34].

During the Tenth Five-Year Plan period (2001-2005), very few PSH plants were constructed and by 2004 the total PSH capacity commissioned was a mere 5.67 GW, less than 1.3% of the total installed generation capacity in the country. However, approval had been given for the construction of a number of large PSH plants. These included the Zhanghewan Plant in Hebei Province with 1,000 MW installed capacity, the Xilongchi Plant in Shanxi Province with 1,200 MW installed capacity and the Bailianhe Plant in Hubei Province with 1,200 MW installed capacity [20].

By the end of 2013, the cumulative operation capacity of PSH in China reached 21.55 GW, with a further 14.24 GW under construction or approved for construction, bring the total to 35.79 GW (see Table 1) [20]. The major locations of PSH plants are the East China, the South China and the North China. The Fengning Plant in Hebei Province which is under construction will be the largest PSH plant in the world with an installed capacity of 3,600 MW [20].

4.2. New policies for PSH plants

The structural reforms to the electrical power sector changed the context for the construction, operation and tariff of PSH plants. As a result, the government issued two new policies which were encapsulated in Documents No. 71 and No. 1571, promulgated in 2004 and 2007 respectively.

4.2.1. Document No. 71 (2004): Policy on the construction and operation of PSH plants

Subsequent to China's electricity market reform in 2002, the principal investors in power generation have been the "Big Five" generation groups[3], local electricity

[3] The "Big Five" generation groups are The China Huaneng Power Group, The China Datang Corporation, The China Huadian Corporation, The China Guodian Corporation and The China Power Investment Corporation.

investment companies and, to a much lesser extent, foreign invested electricity companies. The reforms on the generation side greatly stimulated the enthusiasm of these companies to invest in PSH plants which, in turn, created competition to gain access to the relevant hydro resources. As a result, the capacity of planned PSH plants appeared to be much greater than the demand of the whole electricity system at the time, threatening to lead to the disorderly development of PSH capacity.

In order to promote the orderly development of the PSH to ensure the improvement of the reliability, stability and economy of the grids, in 2004 the National Development and Reform Commission (NDRC) promulgated the *Circular on the Construction and Operation of Pumped Storage Hydroelectricity Plants* (NDRC Energy [2004] No. 71) [31] to regulate the construction and operation of the PSH plants. This document provides that:

(a) PSH plants should mainly serve the grid and be, in principle, constructed and managed by the grid company so as to ensure that they support the needs of the grid;

(b) The construction and operation costs of the PSH plants should be consolidated into the grid company operation costs and approved by the government;

(c) PSH plants invested by the generation companies should subordinate themselves to the overall electricity development plan and participate in the electricity market competition as independent electric power plants.

It is clear that this Circular positioned PSH plants as operational tools of the grid company and gave little consideration to their economic uniqueness.

4.2.2. Document No. 1571 (2007): Electricity tariff policy for PSH plants

Between 2000 and 2004, construction had begun on several large PSH plants, such as the Tongbai, Tai'an, Yixing and Huizhou plants, in order to provide peak regulation and other auxiliary services. By 2006 these PSH plants were soon to be commissioned. There was therefore the need to clarify the tariff policy for those plants that were approved before 2004 when Document No. 71 was issued. It was in this context that the NDRC promulgated Document No. 1517 in 2007 to provide a capacity–based tariff for these newly commissioned PSH plants. This tariff policy was made in the recognition that both the generation companies and the electricity users were beneficiaries of PSH.

The Circular on the Electricity Tariff of Tongbai and Tai'an Pumped Storage Hydroelectricity Plants (NDRC Price [2007] No. 1571) provides that no electricity tariff would be set for those PSH plants approved after the promulgation of Document No. 71 and constructed solely by the grid company. The costs of these plants should be consolidated into the grid operation costs approved by the government. The PSH plants approved before the promulgation of Document No. 71 and for which feed-in tariff (FIT) had not been set would adopt the lease model. The lease cost would be approved by the pricing agency under the State Council on the basis of reimbursing fixed costs and reasonable profits. With respect to the principle of approving the lease price, the document provided that the grid company should pay a 50% share of the lease price and the other 50% price should be borne equally by the generators and the electricity consumers. Further, the 25% lease price paid by generators should be recovered by soliciting bids from thermal power plants for providing electricity for water pumping at the guiding tariffs set by the government. The 25% assigned to the electricity consumers should be recovered through adjusting the electricity retail price. In addition, the document verified that the annual lease prices for Zhejiang Tongbai Plant and Shangdong Tai'an Plant be RMB 484 million and RMB 459 million respectively [30].

4.3. New tariff regimes

These two policy documents led to the development of two new tariff regimes: the transmission and distribution integrative regime, and a lease regime in which the lease price was required to be approved by the government rather than being settled through negotiation, as was the case in the Guangzhou model.

4.3.1. The transmission and distribution integrative tariff model

According to Document No.1571, the PSH plants approved subsequent to the promulgation of Document No.71 should only be invested and operated by the grid company and no FIT would be set for these plants. The construction and operation costs of these PSH plants should be integrated into the grid company operation cost. As such, these PSH plants are actually treated as the assets (or the facilities) of the grid company. Theoretically, these costs could be recovered from the transmission and distribution tariff which is ultimately borne by all power plants and electricity consumers.

The problem is that a number of PSH plants approved after the enforcement of Document No.71 are actually owned by local governments. Since these plants are independent investment entities, they could not be defined as assets of the grid company according to the Corporation Law of the PRC. As such, the costs of the PSH plants could not be integrated into the grid company operation costs. Further, there is, as yet, no independent transmission and distribution tariff mechanism in China. The transmission and distribution tariff currently in China is the difference between the government-determined tariff rate for electricity consumers and the government-determined FIT. In other words, even if the plants are wholly invested by the grid company, the costs of the PSH plants might not be recovered by the transmission and distribution tariff charged by the grid company [34].

4.3.2. The government-approved lease model: Zhanghewan model

According to Document No. 1571, plants operating under a lease model must seek government approval for the lease price. In the case of the Zhanghewan Plant in Hebei province, for example, the lease price approved by the government is RMB 507.46 million per year, including tax. This is based on the investment cost, tax and reasonable profit of the plant associated with the total installed capacity, the plant operation loss, namely the 20%-30% energy conversion loss, is not compensated.

Since the greater the output of the PSH plant, the higher the energy conversion loss incurred, it is understandable that the electricity dispatch operator, which is affiliated to the grid company, has been reluctant to dispatch the PSH plant.

On the other hand, the electricity tariff for water pumping under the Zhanghewan model has been on the low side. Document No. 1571 sets the guiding tariff for water pumping at, for instance, RMB 0.26/kWh in the Shanxi grid and RMB 0.296/kWh in the Shandong grid, and states that generators could decide on their own whether to participate in generation bidding for water pumping or not [32]. The problem is that the coal price had witnessed a dramatic rise since 2003, which had led to an increase in the generation cost for thermal power generators. As a result, the government-approved tariff for water pumping could not recover even the variable generation cost of the thermal power plants. This has inevitably tempered the enthusiasm of the thermal power plants in bidding for generation for water pumping, as evidenced in the case of the Zhanghewan Plant. In 2012, the generation cost of thermal power in the South Hebei Grid region was higher than the bid tariff of RMB 331/MWh approved by NDRC. As a consequence, no generators participated in the bidding.[4]

This lease model is currently applied to a considerable number of PSH plants including the Xilongchi, Taishan and Huizhou Plants. As the capacity tariff (the lease price) under this regime is completely unrelated to the output, it is unfavorable for the PSH plant to play its role in peak and frequency regulation. Further, since the PSH plant income is relatively fixed during its operation period, providing no room for income increase, it is unfavorable for incentivizing the construction of PSH plants. In addition, the revenue of the plant will be greatly diminished when costs increase. Not surprisingly, most plants

[4] Data relating to the Zhanghewan Plan came from interviews carried out by the authors with managers at the plant in October 2013.

that have adopted this tariff model are in difficult financial circumstances, with an average ratio of profit to assets of only 2% [33].

4.4. Summary

Notwithstanding the fact that a number of new projects have been in operation, PSH in China has been overlooked over the past decade, despite it being the primary large-scale energy storage technology utilized worldwide. This is evidenced from the fact that the ratio of cumulative installed capacity of PSH in the country's total has only increased from 1.3% in 2008 to 1.76% in 2013, and the average utilization of PSH units has decreased from 2649 hours to 1419 hours over the period of 2008-2012. The annual average utilization hours of some PSH plants has been a mere 100-200 hours. The lowest was 28 hours. These plants have only played the role of following load in summer, ensuring electricity supply in special periods or in emergency. This phenomenon even exists in areas with serious peaking and power brownout problems. The gap between the actual utilization hours and the designed utilization hours of PSH plants is very large [20]. Evidently, the low efficiency of PSH units has largely arisen from the existing PSH operation and tariff regimes which fail to incentivize or even discourage the investment and operation of PSH plants. As a consequence, PSH is not well utilized as a solution to the challenges of wind power integration in China.

5. New policies issued in 2014

The slow development of PSH in China threatened to constrain the progress of the nation's energy transition. As explained above, the rapid expansion of wind power capacity has not been matched by the utilization of this clean form of energy because of serious curtailment problems. In addition to assisting to solve this deficiency, PSH can also provide a useful outlet for the growing nuclear power capacity at times of low demand. In recognition of the limitations of the prevailing operating and tariff regimes governing

PSH development in the country, the government issued new policies in July and November 2014 to address the tariff, construction and operation of PSH plants.

5.1. Document No. 1763 (2014): Revised electricity tariff for PSH plants

The *Circular on the Improvement of Feed-in Tariff Formation Mechanism for Pumped Storage Hydroelectricity* (NDRC Price [2014] No. 1763) issued in July 2014 provides that a two-part FIT will be implemented for new PSH plants as well as for the existing PSH plants for which the FIT has yet to be approved. The FIT is to be approved in accordance with the principle of reasonable cost and permitted return. While the cost includes construction and operating cost, the permitted return is to be approved in light of the risk free rate of return (long-term Treasury rate) plus 1%-3% risk return rate [34]. This provision ensures that investors will not lose money as long as their PSH plant plays its role of reserve capacity, which is undoubtedly helpful for stimulating investment.

The document further provides that, firstly, the two-part FIT reflects mainly the value of PSH capacity in providing auxiliary services. The benchmark capacity-based FIT is to be applied gradually to newly commissioned PSH plants. Secondly, the generation-based FIT reflects the value realized through the generation of the PSH plant in peak shaving and valley filling and is to make up for the variable costs such as energy loss between water pumping and power generation of the PSH plants. This generation-based FIT is the same as the benchmark FIT for local coal-fired units, including the supplementary tariffs for desulfurization, denitrification and dust elimination. Thirdly, the electricity tariff paid to the grid company for providing water pumping is to be 75% of the benchmark FIT for coal-fired units [34]. Apparently, this provision gives consideration to the fact that the efficiency of PSH system is typically 70%-80%.

In addition, the document encourages the deployment of market tools. It states that in regions with good conditions, PSH project owners, generation output, capacity tariff, water pumping tariff as well as FIT could be determined through bidding. Further, the capacity tariff and efficiency loss of PSH plants should be consolidated into the overall accounting of local provincial or regional grid operation costs and taken into consideration in the adjustment of electricity retail tariffs.

5.2. Document No. 2482 (2014): More policies on PSH development

In November 2014, the NDRC promulgated the *Opinions on the Promotion of Healthy and Orderly Development of Pumped Storage Hydroelectricity* (NDRC Energy [2014] No. 2482). With regard to PSH development policies, this document provides that at the present stage, the construction and management of PSH plants should be mainly undertaken by the grid company, as before, but mechanisms to attract other sources of commercial capital should be gradually established. The document also states that the government will explore options for coordinating and supporting investment and for a tariff regime for PSH plants and other power sources in new energy bases are to be explored. In addition, different mechanisms for realizing PSH plant value are to be explored which would reflect its value to their stakeholders. In summary, this document does not appear to outline specific new policies for PSH, although it does identify policy issues that need to be addressed urgently [35].

6. Policy recommendations

Whilst these two new policy documents demonstrate that the government recognizes the urgent need to accelerate the development of PSH, they do not go far enough and fail to address a number of important issues. Without further measures being implemented, the PSH sector will not be able to play its much needed role in assisting China's energy transition. Our recommendations for further policy actions are:

- Remove restrictions on investment in PSH;

- Establish time-of-day tariffs for generators;
- Expand regional grid connection;
- Establish a market for ancillary services.

6.1. Remove the restrictions on investments in PSH

Under the current regulations, the grid company and its subsidiaries dominate the investment in new PSH capacity. This is consistent with the current approach to treat the PSH plant as an integral part of the transmission system. However, the PSH plant has its own unique economic value and at least some of these economic benefits can be translated into financial revenues. This would enable PSH plants to be treated as distinct corporate entities with a defined revenue stream and create interest from commercial enterprises to invest in new PSH capacity. Although the new policies issued in 2014 opened up investment in new PSH capacity to commercial investors, it is not clear whether they would be permitted to be controlling shareholders or not. Given that more competition in investment is necessary to promote PSH development, it is recommended that commercial investors are allowed to be controlling shareholders.

6.2. Establish time-of-day tariffs for generators

Although the recent two-part tariff ensures the recovery of investment cost, it fails to address the profits of the grid company. If time-of-day tariffs could be put in place, the enthusiasm for PSH plant investment would be greatly stimulated. Although there are time-of-day tariffs applicable for certain classes of end users in China, there is no corresponding tariff regime applicable to power plants. In the absence of a real-time power market and time-of-day generator tariffs in China, the generators receive a uniform tariff irrespective of the time of generation. This does not capture the time value of electricity and acts as a disincentive to energy storage. In the absence of time-of-day or real-time tariffs for generators, PSH plants incur financial losses if they engage in energy arbitrage (i.e. store energy during off-peak time and generate during peak time) due to the energy storage loss.

While real-time electricity market would enable the PSH plants to realize the time value of electricity to the maximum extent, given the complexities associated with establishing a real-time electricity market in a country like China, it is recommended to offer time-of-day tariffs for generators as a short-term measure. This would reduce the instances of excess generation in off-peak times as some of the thermal power plants would refrain from generation if the off-peak tariff is below their variable cost.

On the other hand, wind farms will continue to generate during off-peak times because of the insignificant variable cost in wind power generation. PSH plants would be encouraged to purchase electricity at the lower off-peak tariff for water pumping and offer its output at a higher tariff during the peak time. The time-of-day tariff can be set by the regulator to simulate the real time electricity prices after taking into account the variable cost of generation in off-peak time and peak time in different Chinese provinces.

6.3. Expand regional grid connection

China's regions of abundant wind and solar resource are concentrated in the 'Three Northern Regions' (Northeast China, North China and Northwest China) which do not possess natural advantages for constructing PSH plants [23]. In contrast, the central and east load centers have very rich peak regulation power sources and capability in the form of hydroelectricity. In the current context where the share of PSH is low, it is necessary to complement the peak regulation resources across regional grids through the expansion of grid connection so as to greatly improve the overall benefit of PSH plants and their capacity to support renewable energy.

6.4. Establish a market for ancillary services

Growing wind power penetration results in an increased demand for ancillary services such as spinning reserve, contingent reserve, load following capability and frequency regulation. PSH plants have the technical capability to offer these ancillary services in an economically competitive manner compared to thermal power plants. However, there is no mechanism to reward the PSH plants for providing these ancillary services to the system operators at present. The grid company, which either leases or owns PSH plants, is not in a position to derive additional revenues for the ancillary services provided by the PSH plants. By creating a market for ancillary services and allowing the cost of ancillary services to be passed down to end users and inflexible generators, the grid company would be encouraged to utilize the PSH plants more often.

This would also compensate the grid company for incurring the energy storage loss associated with the operation of PSH plants, as well as enhance the capability of the grid company to utilize wind power and minimize the wind power curtailment. Although the Chinese government is contemplating the creation of an ancillary service market, it has not yet been established in a transparent manner. The integration of PSH plants to the ancillary services market and the compensation mechanism need to be reformed to facilitate the participation of PSH plants in the ancillary services market.

7. Concluding remarks

The large scale development and the increasing ratio of wind power in the total installed capacity in China has brought and will continue to bring great challenges to the grid in peak and frequency regulation. Internationally, PSH is by far the most widely used method as it is the most technologically advanced, widely available resource to provide balancing and integration of variable renewable technologies. PSH also provides a market for base-load nuclear power at times of low demand. In these ways, PSH can play a vital role in supporting the energy transition in China and in other countries with potential for developing such hydroelectricity resources.

While the benefits of expanding pumped storage capacity in China are clear, for many years the operation and tariff regimes have not provided an effective means of achieving this goal. PSH plants have been positioned as operational tools of the grid company and little consideration has been given to their economic uniqueness. Instead, government regulations and policies have required that PSH plants be constructed and managed by the grid company and that the operating cost be integrated into the grid company operating cost. Although the recently revised policies have made improvements with regard to the PSH tariff regime, more policy changes are needed to support the timely development of PSH in China.

To this end, three research directions can be identified: (a) To examine those PSH operational and tariff mechanisms currently implemented to good effect in other economies, particularly in the EU member countries; (b) To comprehensively assess the value of ancillary services and their benefits to all relevant parties so as to provide the basis for pricing ancillary services as well as revenue sharing; (c) To examine the institutional constraints to the development of creative PSH policies.

The challenges and lessons that this paper has identified in the case China are relevant in other countries that are promoting the deployment of wind energy as part of their strategy for the energy transition. Of particular importance is the need to assess the value of PSH to the entire electricity system and to put in place incentives that reward enterprises for constructing and operating PSH plants.

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