



**Asia-Pacific
Economic Cooperation**



APEC Sustainable Energy Center

Research on Integrated Multi-energy System to Improve Energy Efficiency and Enhance Technological Progress of Renewable Energy in the APEC Region



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Executive Summary

The world couldn't develop without energy. The changes happening on resources, environment and development strategy in the world today, force all relevant links in the energy field including production, transportation and usage to be more green, high-efficient and low-carbon. It is an evitable developing direction for the energy system to become more and more intensive, refined and diversified. On one hand, along with the development of renewable energy, the supply side of energy is now embracing a massive entry of some clean but discontinuous renewable energy. How to make the renewable energy friendly achieve grid connection while reducing the occurrence of “wind power curtailment, solar power curtailment”, is the issue that urgently needed to be solved for the further development of renewable energy. On the other hand, the user requirements on energy products become more and more diversified and a higher demand on energy efficiency is also taking place. Methods like integrated improvement on “electricity, heating, cooling” energy system, integration and mutual aids are very important for a reasonable usage on distributed resource from user side, for satisfying terminals' differentiated energy needs as well as for enhancing efficiency. These are the background and request that make the integrated multi-energy system possible and now it has become a hot issue that attracts the whole world's attention.

Integrated multi-energy system is an effective way to improve the comprehensive efficiency of energy system, enhance the coordinating capability of energy supply and demand, as well as facilitating the nearby digestion and high-efficient use of clean fossil and renewable energy. In 2014, the 22nd APEC Economic Leaders' Meeting approved the goal as “double the share of renewable energy including in power generation by 2030 in APEC's energy mix than that in 2010”. And driving the development of integrated multi-energy system in APEC regions is one of the substantial approaches to achieve this target.

Therefore, APEC Sustainable Energy Center applied for an APEC self-funded project (EWG 10 2018S - Research on Integrated Multi-energy System to Improve Energy Efficiency and Enhance Technological Progress of Renewable Energy in APEC Region), which aims at a better promotion and spreading on advanced technology related to integrated multi-energy system for APEC, so as to contribute to the development of utilization level on cleaner fossil energy and enhance technological progress of renewable energy in the APEC region.

Chapter I: Introduction of Integrated Multi-energy System

1.1 Connotation and characteristics of Integrated Multi-energy System

In today's world, the forms of primary energy sources include coal, petroleum, natural gas, nuclear energy, hydroenergy, wind and solar energy etc. And among all these mentioned energies, coal, petroleum and natural gas belongs to fossil energy, of which the usage has strongly driven the industrial development and civilization progress, while in the meantime serious problems such as exhaustion of energy reserve, environmental pollution and a sharp rise on carbon emission. The traditional energy development model that relies on fossil energy is not sustained; therefore it is one of the most principal goals to develop multi-energy forms, especially the renewable ones with clean technology and decarbonization, to optimize production and consumption structure of energy in order to achieve energy saving and environmental protection.

The traditional energy service originates from USA in the middle of the 20th century. Different types of energy have quite obvious boundaries. The rate of dispatch, control and utilization on energy is rather low, and it couldn't allow new resources with large-scale and high penetration rate like wind or solar energy to switch in. Under the background that the renewable energies have made fast development, a higher requirement on the flexibility and storage capability of existing energy system is raised due to the fluctuation and difficulty of allochthonic digestion of the renewable energies. Different energy systems show different performance characteristics. Traditional fossil energy is stable and controllable. While on the other hand, although wind and solar energy have obvious advantage like being green, environmentally protective and inexhaustible, they are rather intermittent and undulant due to the wind and light density, and their output power is highly depending on spatio-temporal distribution. In order to guarantee the total demand of terminal users on energy, all forms of resources can mutually replace and make up the deficiencies for one other. They also can largely reduce or even eliminate the uncertainty happening in the energy supply process so as to facilitate the digestion of renewable resources and to improve the comprehensive rate of the energy system. Being the important developing result of a deep combination between traditional and renewable energy systems, here comes the "integrated multi-energy system".

1.1.1 Connotation of Integrated Multi-energy System

The “Integrated Multi-energy System” is an evolved form of energy supply method. It is a pattern that covers multiple kinds of energy, offers diversified energy products like electricity, heating and cooling; a pattern that satisfies various model of energy supply and demand in order to achieve a most effective way for coupling integrated supply of energy. The diagrammatic sketch of the “Integrated Multi-energy System” is shown in Fig. 1-1.

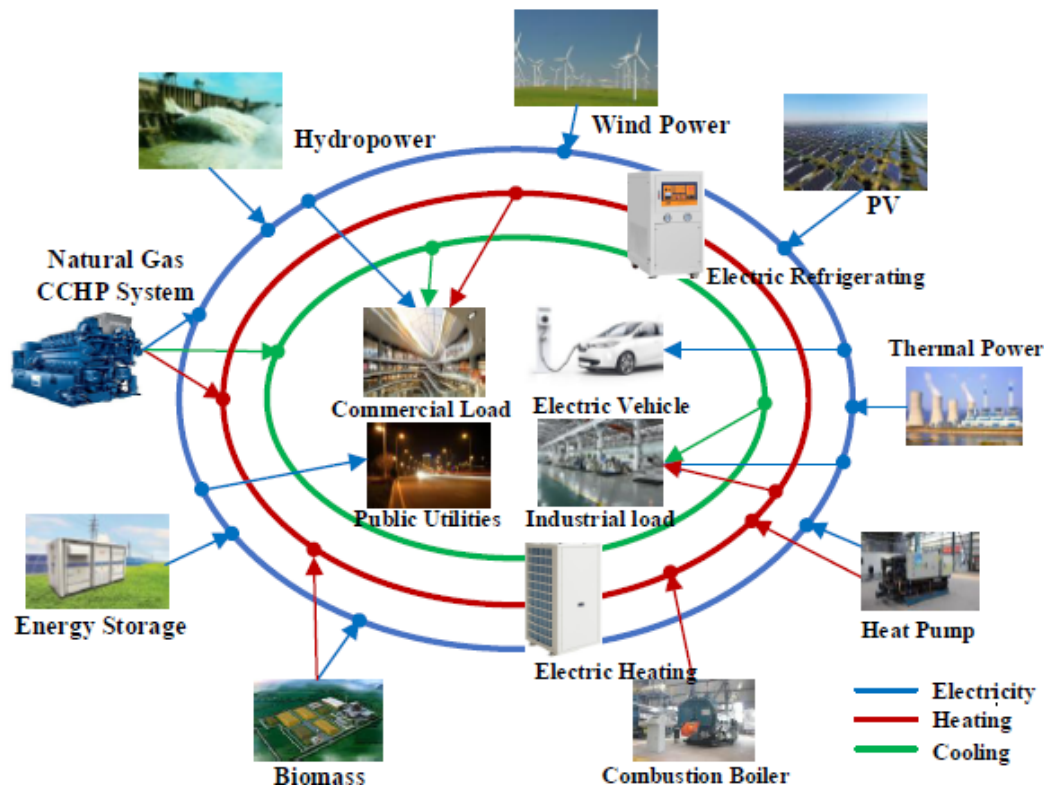


Fig. 1-1 Schematic diagram of Integrated Multi-energy System¹

The “Integrated Multi-energy System” is not simply adding or combining multiple forms of resources. It is an extension based on traditional energy applications and has improved its disadvantages. The System shows the concept of “consolidated energy, comprehensive consideration, and an all-in-one strategic idea”. The connotation of the “Integrated Multi-energy System” includes three aspects²:

¹ DONG Zhenbin, Kuai Dizheng. Research and practice of optimizing energy system with multi-complementary integration [J]. Power Demand Side Management, 2018, 20(01): 46-49. (in Chinese)

² HE Yongjian. Integrated Multi-energy System Opening up a New World of Energy Revolution[N]. CHINA ENERGY NEWS, 2017-7-17(008) (in Chinese)

First of all, it covers a variety of energy types: not only traditional ones, but also new and renewable energy.

Secondly, it offers a diversity of energy products: based on the demand of user side, it provides a comprehensive supply like electricity, heating, cooling and gas.

Thirdly, it allows multiform model of energy supply and demand: models that are closer to users, satisfied to their special needs, and models with coupling integration and supply-demand interaction.

The core objective of the “Integrated Multi-energy System” is to solve the interaction, coordination and sharing issues between multiple energies so as to establish an open, interactive and smart energy supply system. In actual practice, the “Integrated Multi-energy System” organically coordinates and optimizes links on production, transportation, distribution, transfer, storage and consumption of energy by an improved design, dispatch and management in the process of planning, construction and operation. In this way, different forms of energy will co-exist in order to realize the goals to comprehensively combine and use in a high efficient way.

1.1.2 Main characteristics of Integrated Multi-energy System

A cleaner and more high-efficient energy intergration will be created through the complementation among energy of multiple types as well as energies from different regions, especially the combination of traditional and renewable resources. The “Integrated Multi-energy System” has 6 characteristics as follows:

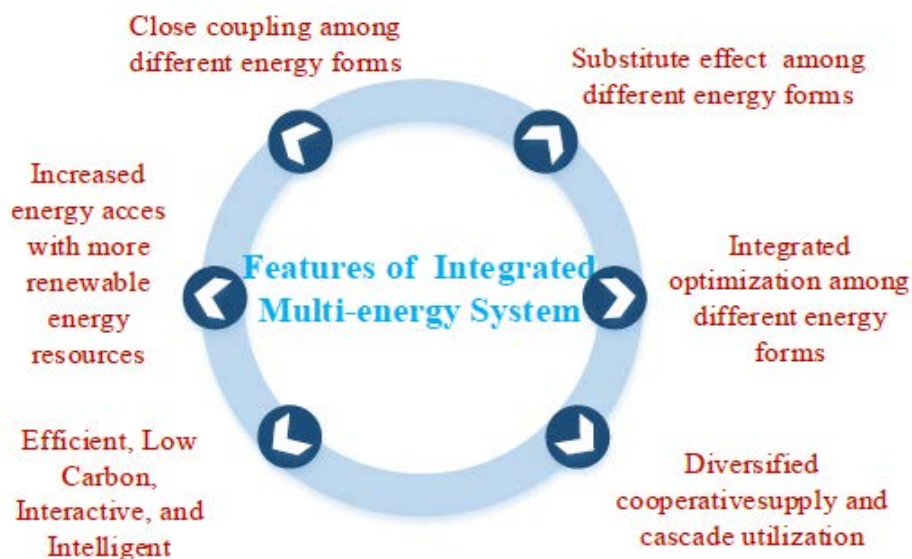


Fig. 1-2 Features of Integrated Multi-energy System

(1) All forms of energy are closely coupled together

The operational mode of traditional energy system is relatively independent, and there are generally strong barriers between the subsystems. Whereas in the “Integrated Multi-energy System”, the source, grid and load of multi-energy are deeply connected and closely interacted, while in the meantime, the pipe network of petroleum, natural gas and the generation grid of renewable energy in this system are interconnected together on critical energy panel point so they can be flexibly switched to achieve equal exchange and resource sharing. As a result, in various aspects of the energy industry like production, transportation, storage and use, all energy forms are not divided but an organically systemized and integrated ensemble.

(2) An obvious substitution effect exists among all energy forms

In the integrated multi-energy system, there are non-renewable and traditional fossil energy as well as renewable ones like wind and PV. The renewable and non-renewables are not just simply mixed together, but with a coordinating control to bundling or to make integrated external output. On the external perspective, the integrated multi-energy appears to be stable and continuous. On the internal point of view, the power output curve caused by the volatility of renewable energy is stabilized by thermal power, energy storage and hydropower. All energies involved in the integrated multi-energy system own the possibility of interconversion and replacement.

(3) Integrated optimization

The integrated multi-energy system combines multiple types of energy like wind, solar, hydropower, thermal power etc., making it possible to convert between transportation network and path as well as the energy product need from user side for electricity, cooling and heating through cooling-heating-electricity combined plant, hydrogen manufacturing/gas production, electricity-heating and electricity-cooling devices. In the coordinating planning layout and operation control, it's possible to achieve an intensive control to reach the integrated result. Therefore, integrated optimization is one of the objectives and critical characteristics.

(4) Diversified coordinating supply and gradient utilization

The terminal consumption of energy mainly includes energy products like cooling, heating and electricity. The multi-energy integration makes a coordinated interaction as “source-grid-load-storage” to change the energy production and supply from singular to multiplex coordinating. By using means like natural gas distributed combined cooling, heating and power system (CCHP) and micro grid, an integrated multi-energy input system is built, and it achieves the synchronized multi-energy supply involving traditional energy and wind power, solar energy, geothermals and biomass energy. The system improves the distribution of electricity,

gas, heating and cooling, and makes use of all these resources based on grade. The integrated multi-energy system can satisfy diversified energy supply within the system, while effectively improving the economic benefits of the project itself.

(5) High efficiency, low carbon, interaction, open, smart

The integrated multi-energy system effectively provides energy efficiency, and reduces the carbon emission of the system by complementing advantages of sources, optimizing the grid structure, along with proactive control and services. Meanwhile, the system comprehensively makes use of technologies like energy internet, information physical system, big data and response on user side, and it's an interactive, open and intelligent system.

(6) Be adapted to higher penetration rate for renewable energy to switch in

In recent years, the issue of wind power and solar power curtailment has become quite serious. Electricity generated by wind and PV often suffers from randomness and fluctuation therefore causes a severe negative effect on the stability of power grid. Implementation of multi-energy integration is to coordinate power generated by wind, PV, thermal and hydro energy, and complements with energy storage and pumped-storage devices to form an energy supply that matches users' load. In this way, the local digestion and bundling transmission can be effectively improved, and it also can meet a higher switching-in rate for renewable energy.

1.2 Study and application progress of Integrated Multi-energy System

Due to the fact that the "Integrated Multi-energy System" is an effective way to improve comprehensive efficiency for energy system, to improve coordination capability of power supply and demand and to promote an effective way for cleaner and renewable energy to achieve a nearby digestion and high-efficient usage rate, Europe and many economies in Asia-Pacific regions have initiated relevant academic and applicable studies. Especially in China, since 2011, some areas in western China have severe issues on wind power, solar power and hydropower curtailment after a massive development of renewable resources. In order to solve the electricity digestion problem of renewable energy, China has launched a series of industrial policies to promote the development of integrated multi-energy, and has published the first batch of 23 demonstration projects on integrated multi-energy system in 2017.

1.2.1 Europe

In 2005, Swiss Federal Institute of Technology Zurich (ETH)³⁴⁵ has taken on the project study “Vision of Future Energy Networks”. The study believes that the future energy grid can be mutually interconnected by electricity, heating, cooling and natural gas networks. It suggests a concept called “energy hub” which will act as the transfer unit for multi-energy and load requirements in order to achieve multi-energy transfer and distributed energy’s transformation and storage.

For achieving the target of 80% power supply from renewable energy in 2050, Germany has actively tested integrated multi-energy plan. In 2008, the Federal Ministry for Economic Affairs and Energy chose 6 model regions out of the smart grid to run a 4-year E-Energy technical and innovative promotion plan⁶⁷ with a total investment of 140 million euros. The project focused on developing the energy system based on ICT and the goals are: achieve safe supply, high efficiency and climate protection through the application of digital networks; use model ICT technology to realize optimization on power supply system; create more interdisciplinary jobs in the fields of renewable energy and telecommunications; offer new market for high-tech solutions; promote the liberalization and decentralization in the energy market.

As an island, the power system of UK only get connected to electricity and gas grid on European Continent by high-voltage DC line and gas pipelines in a rather small capacity. The British government has long been working on building up a safe and sustainable energy system. Besides integrated electricity/gas system⁸ on the national level, the study and application on distributed integrated energy system at community scale in UK have received big support. For example, Department of Energy & Climate Change (DECC) of UK and the innovation agency- Innovate UK (formerly known as TSB) have worked with corporations to invest quite a few studies and applications on integrated regional energy system. In April of 2015, Innovate UK

³ Favreperrod P. A vision of future energy networks[C]// Power Engineering Society Inaugural Conference & Exposition in Africa. IEEE, 2006.

⁴ GEIDL M, KOEPPPEL G, et al. Energy hubs for the future[J]. IEEE Power Energy Magazine, 2007, 5(1): 24-30.

⁵ SUN Hongbin, PAN Shaoguang, GUO Qinglai. Energy management for multi-energy flow: challenges and prospect[J]. Automation of Electric Power System, 2016,40(15):1-8+16. (in Chinese)

⁶ http://smartgrid.epri.com/doc/05_E-Energy%20German%20Smart%20Grid%20Projects.pdf

⁷ WANG Xiwen, WANG Yezi. Introduction of German smart grid “E-Energy” project promotion[J]. Power Demand Side Management, 2011, 13(4): 75-76. (in Chinese)

⁸ Qadrdan M, Chaudry M, Wu J, et al. Impact of a large penetration of wind generation on the GB gas network[J]. Energy Policy, 2010, 38(10):5684-5695.

set up “Energy Systems Catapult”⁹ in Birmingham and invested 30 million pounds per year to support UK companies for studying and developing integrated energy system.

1.2.2 United States

In 2001, United States Department of Energy raised the development plan called Integrated Energy System (IES)¹⁰. The objective was to increase clean energy supply and usage percentage in order to further improve the reliability and economic effect of social energy supply systems. In the IES plan, the critical point is to promote the progress and application of Distributed Energy Resources (DER) and Combined Heating and Power (CHP) technology.

In December of 2007, the United States enacted *Energy Independence and Security ACT of 2007 (EISA)* and clearly required the main energy supply links should start the Integrated Resource Planning (IRP)¹¹.

The US government has subsidized the “Future Renewable Electric Energy Delivery and Management” (FEEDM) project in 2008¹². The project uses power electronics and high-speed digital communication as well as distributed control technology to form an intergrated multi-energy structure from all kinds of distributed power, energy storage devices and load by solid transformer.

In 2003, the National Renewable Energy Laboratory of the United States established “Energy Systems Integration Facility (ESIF)”¹³ and raised the point that energy systems integration is an approach to solving big energy challenges that explores ways for energy systems to work more efficiently on their own and with each other

1.2.3 Japan

⁹ <http://www.catapult.org.uk/energy-systems-catapult>

¹⁰ DOE of United States. GRID 2030. A national vision for electricity’s second 100 yeas[EB/OL]. <http://www.ferc.gov/eventcalendar/files/20050608125055-grid-2030.pdf>

¹¹ Energy independence and security ACT of 2007 [EB/OL]. <http://www.ferc.gov/eventcalendar/files/20050608125055-grid-2030.pdf>

¹² Huang A Q, Crow M L, Heydt G T, et al. The future renewable electric energy delivery and management (FREEDM) system: The Energy Internet [J]. *Proceedings of the IEEE*, 2011, 99(1):133-148.

¹³ <https://www.nrel.gov/esif/labs.html>

Japan is a economy that greatly relies on energy importation therefore is the earliest economy in Asia that starts to study Integrated Energy System (IES).

In September of 2009, the Japan government announced their emission reduction objectives on year 2020, 2030 and 2050, and the intention to put efforts into building an integrated energy system to cover the whole economy so as to optimize energy structure and improve energy efficiency while facilitating the exploration on renewable energy in a large scale. Under the boosting of the government, main energy study agencies in Japan have all started such research and have generated different study solutions. For example, the JSCA (Japan Smart Community Alliance)¹⁴, launched and founded in April of 2010 by NEDO, mainly dedicates in the study and demonstration on Smart Community technology. The Smart Community achieves an all-in-one system integration of transportation, water supply, information and medical treatment based on the community integrated energy system (including electricity, gas, heating power, renewable resources etc.). Tokyo Gas came up with a more advanced solution on integrated energy system¹⁵. On the basis of traditional integrated energy system (electricity, gas and heating power), a hydroenergy supply grid which covers the whole society will be built. In this way, a terminal integrated energy system is formed and it will be composed by terminals of energy network, different energy using devices and transferring-storing units of powers.

After the big earthquake in 2011, all walks of life in Japan paid more attention to the development of distributed energy and micro grid, and they have even extended the meaning of these. They've tried to build distributed energy system in core city areas like Shinjuku, Harajuku and Roppongi based on smart grid in the purpose of big improvement on the reliability of power infrastructure and the capability against catastrophic risks. The representing projects include: distributed energy system in Hachinohe area of Aomori Prefecture, ECO energy project in Kyoto, distributed energy system at World Expo in Aichi Prefecture, municipal-type energy supply syetem in Roppongi¹⁶.

¹⁴ NAKANISHI H. Japan's approaches to smart community [EB/OL]. (2014-10-09) [2017-03-01]

¹⁵ Tokyo Gas. Challenge for the future society: smart energy network [EB/OL]. http://www.tokyo-gas.co.jp/techno/challenge/002_e.html.

¹⁶ REN Hongbo, WU Qiong, QIU Liuliang, etc. An Analysis of Configurations and Operational Status of Japan's Distributed Energy Systems and What Can be Learned for China[J]. SINO-GLOBAL ENERGY, 2015, 20(07):9-14. (in Chinese)

1.2.4 Canada

In June of 2009, the Parliament of Canada reviewed and approved the *Combining Our Energies: Ingegrated Energy Systems for Canadian Communities*¹⁷ that aimed at facilitating the relevant studies on integrated energy system in the economy. Later in the September of 2009, the Energy Committee of the Cabinet enacted the guidelines on *Integrated Community Energy Solutions: a Roadmap for Action*¹⁸, in which clearly stated that Integrated Community Energy System (ICES) covering all communities was a critical measure to Canadian Government for dealing with the global energy crisis and fulfilling its goal for greenhouse emission reduction in 2050. The guideline also mentioned that the government would promote the relevant ICES study, spread ICES related technologies, and build up practical ICES projects. It is listed as the national energy strategy for 2010-2050. Besides the input for ICES model projects in Canada, the government also launched various important research topics for all-around study relating to integrated energy system and technologies, such as: EquilibriumTM Communities Intiative, Clean Energy Fund, ecoENERGY, Building Canada Plan etc.

1.2.5 Singapore

In 2009, Singapore launched the Intelligent Energy Systems (IES) project¹⁹. After this, Singapore has made it to one of the advanced countries with smart grid technology in the world. IES intelligent experiment project contains the automatic upgrade and digital remote control system for electricity transmission system. Its implementation has been divided into 2 phases. The critical phase I is about the construction of AMI and communication system. Phase II emphasizes one the application of smart grid. In 2016, IC Power PTE Ltd reached a 7.4-million-dollar cooperation on grid sensor and data analysis with 3M Company from the United States. Singapore also worked with GE to implement the digitalization of transmitting substations.

1.2.6 China

¹⁷ Combining our energies-integrated energy systems for Canadiancommunities[EB/OL].
http://publications.gc.ca/collections/collection_2009/parl/xc49-402-1-1-01e.pdf

¹⁸ Natural Resources Canada. Integrated community energy solutions: a Roadmap for action [EB/OL].
http://oee.nrcan.gc.ca/sites/oee.narcan.ga.ca/files/pdf/publications/cem-cme/ices_e.pdf.

¹⁹ Denis Gross. Focus on Smart Grid City Singapore [J]. LOW CARBON WORLD, 2011(08):68-70. (in Chinese)

Since 2011, along with massive development on renewable energy in China, wind power curtailment, solar power curtailment, and hydropower curtailment have become very serious in western regions, In order to solve the digestion on renewable energy like wind power, PV and hydroenergy, China has released a serie of industrial policies as shown in Table 1-1 that can promote the development of integrated multi-energy.

Table 1-1 Relevant policies in China regarding Integrated Multi-energy (2011-2018)²⁰

No.	Policy Name	Releasing Time
1	<i>Guidance Regarding Developing Distributed Energy on Natural Gas</i> [No. 2196 NDRC Energy(2011)]	October 9 th 2011
2	<i>Temporary Administrative Measures on Distributed Generation</i> [No. 1381 NDRC Energy(2013)]	July 18 th 2013
3	<i>Implementing Regulations of Distributed Energy Demonstration Projects on Natural Gas Distributed Energy</i> [No. 2382 NDRC Energy(2014)]	October 23 rd 2017
4	<i>Guidance Regarding the Promotion of Smart Grid Development</i> [No. 1518 NDRC Operation(2015)]	July 6 th 2015
5	<i>Guidance Regarding Promoting the Construction of New Energy Micro Grid Demonstration Project</i> [No. 265 NEA New Energy(2015)]	July 13 th 2015
6	<i>Guidance Regarding Promotion on Developing “Internet+” Intelligent Energy</i> [No. 392 NDRC Energy(2016)]	February 25 th 2016
7	<i>Suggestions on the Implementation of Facilitating Integrated Multi-energy System Demonstration Projects</i> [No. 1430 NDRC Energy(2016)]	July 4 th 2016
8	<i>Guidance Regarding the Promotion Technological and Industrial Development on Energy Storage Technique</i> [No. 1701 NDRC Energy(2017)]	September 22 nd 2017

In December of 2016, National Development and Reform Commission and National Energy Administration jointly published and printed *Energy Production and Consumption Revolution Strategy (2016-2030)*. The strategy brought up the objective to fully establish “Internet+” intelligent energy; reinforce the smart construction of power grid to effectively connect to oil and gas pipeline, heating pipeline and other nergy grids; promote the interconnection of multiple types of energy flow, and transformation of different energy forms; build up a coordinated “source-grid-load-storage” and integrated multi-energy network.

On January 25th of 2017, China National Energy Administration (NEA) published *Notification Regarding the First Batch of Integrated Multi-energy System Demonstration Projects [No. 30 NEA Planning (2017)]* and the first batch of integrated multi-energy system demonstration projects was announced. There are 23 projects arranged in this demonstration

²⁰ <http://www.nea.gov.cn/policy/tz.htm>

plan, among which contains 17 Integrated Multi-energy Systems at User Side, and 6 Integrated Multi-energy Systems at Power Source Side.

Table 1-2 First batch of Integrated Multi-energy System demonstration projects in China (Jan. 2017)

Mode I: Integrated Multi-energy System at End-user Side	
NO.	Project Location
1	Beijing Lize Financial Business District, Beijing
2	Guyuan County, Zhangjiakou, Hebei Province
3	Langfang Economic Development Zone, Langfang, Hebei Province
4	Xianghe County, Langfang, Hebei Province
5	Datong Economic & Technical Development Zone, Datong, Hebei Province
6	Zhalute Zhahazhuoer Industrial Park, Tongliao, The Inner Mongolia Autonomous Region
7	Suzhou Industrial Park, Suzhou, Jiangsu Province
8	Chengnan Economic New Zone, Gaoyou, Jiangsu Province
9	Hefei Airport Economic Demonstration Area, Hefei, Anhui Province
10	Qingdao Economic Development Zone, Qingdao, Shandong Province
11	Future Science and Technology City, Wuhan East Lake High-tech Development Zone, Wuhan, Hubei Province
12	Shenzhen International Low Carbon City, Shenzhen, Guangdong Province
13	Jingbian Industrial Park for Comprehensive Utilization of Energy and Chemical Industry, Yulin, Shanxi Province
14	Yanan New town, Yanan, Shanxi Province
15	Ansai District, Yanan, Shanxi Province
16	Fuping County, Weinan, Shanxi Province
17	The Xinjiang Production and Construction Corps Twelfth Division, Xinjiang Province
Mode II: Integrated Multi-energy System at Power Source Side	
NO.	Project Location
1	Zhangbei County, Zhangjiakou, Hebei Province
2	Tumoteyouqi, Baotou, The Inner Mongolia Autonomous Region
3	Kala Town, Muli County, Liangshan, Sichuan Province
4	Longmen Economic & Technical Development Zone, Hanchen, Shanxi Province
5	Geermu county, Haixizhou, Qinghai Province
6	Hainanzhou, Qinghai Province

1.2.7 APEC Projects

Up to 2018, APEC projects applied by APEC economies in the field of integrated multi-energy are listed in Table 1-3. In order to boost the concentrated integration and high-efficient use of new energy and renewable energy in APEC regions, 10 economies including China, United States, Chinese Taipei, Thailand, Russia, Japan, Australia, Chile, New Zealand and Viet

Nam etc. have totally applied 22 APEC Projects regarding integrated multi-energy from 2006 to nowadays. The projects involve Smart Grid, Integrated Energy System, Distributed Energy and Integrated Multi-Energy System etc.

Fig. 1-3 shows the distribution status of applied economy in the integrated multi-energy field. In total there are 10 economies applied relevant projects during 2009-2018. China and United States are the two economies that declared the most projects in the field with respectively 5 and 4 items (2 of them were jointly applied with Chinese Taipei); Thailand and Chinese Taipei separately applied 3 items (2 of them were jointly applied with United States); Russia applied 2 items, while one item was declared by 5 other economies respectively by Australia, Chile, Japan, New Zealand and Viet Nam.

(1) Most of the researches were related to the key word “Smart”, including “smart grid”, “Intelligent microgrid”, “grid integration”, “energy smart community”, “smart DC community” and “green energy smart farm”. There are 14 relevant researching projects in total (and “smart grid” owns the most related project, 7 of them were of this category).

(2) The key words that are related to “integrated energy” are “grid-interconnection”, “integrated energy system” and “integrated multi-energy system”. 3 projects were related to them.

(3) 3 projects used “distributed energy” as key word.

(4) 2 projects used “multi-energy” as key words.

We can see that “smart grid” has always been the critical and hot point of researches in APEC regions. Although besides China, other economies haven’t adopted the concept “integrated multi-energy”. They still widely develop the application research and practical promotion in this field from aspects like “integrated energy”, “distributed energy”, “multi-energy”.

Table 1-3 Summary of APEC projects in the field of integrated multi-energy (2006-2018)²¹

NO.	Year	Proposing Economy(ies)	Co-Sponsoring Economies	Project No.	Project Title
1	2009	United States	Australia; Indonesia;Japan; Singapore; Chinese Taipei; Thailand; Viet Nam	EWG 01 2009S	Using Smart Grids to Enhance Use of Energy Efficiency and Renewable Energy Technologies
2		Japan	New Zealand; United States	EWG 02 2009	Addressing Grid-Interconnection Issues in Order to Maximize the Utilization of New and Renewable Energy Sources
3		Russia	Canada; Japan; Korea; Singapore; Chinese Taipei; Thailand; United States	EWG 15 2011A	Piloting Smart-Microgrid Projects for Insular and Remote Localities in APEC Economies
4	2011	China	Japan; Korea; Russia; Chinese Taipei; Thailand	IST 01 2011A	Cooperative Study on Efficient Renewable Resources Integration and Distribution Technologies for Smart Grid Construction
5		United States	China; Japan; Korea; Chinese Taipei	CTI 30 2011T	Workshop on Regulatory Approaches to Smart Grid Investment and Deployment
6		Viet Nam	New Zealand; Chinese Taipei; United States	EWG 05 2012A	Small Hydro and Renewable Grid Integration Workshop
7	2012	China	Australia; Chile; Hong Kong, China; Indonesia; Korea; Chinese Taipei; Thailand; United States	EWG 04 2012A	Study of Demand Response's Effect in Accommodating Renewable Energy Penetration in the Smart Grid
8		New Zealand	Chinese Taipei; Thailand; United States	EWG 08 2012	Urban Development Smart Grid Roadmap - Christchurch Recovery Project
9		Russia	China; Indonesia; Japan; United States	EWG 09 2012	Combined Heat and Power (CHP) Technologies for Distributed Energy Systems
10	2013	China	Canada; Hong Kong, China; Singapore; Thailand; Japan; New Zealand; United States	EWG 03 2013A	Building Code Harmonization in Energy Smart Community
11		Thailand	Chinese Taipei; United States; China; Hong Kong, China; Malaysia; Indonesia; Viet Nam	EWG 06 2013A	APEC Smart DC Community Power Opportunity Assessment
12	2014	Thailand	China; United States	EWG 07 2014A	Realization of APEC Low Carbon Model Town through Smart Grid Development (LCMT-SGD)
13		United States	Canada; Singapore	EWG 02 2014S	Cyber-Energy Nexus Study - Opportunities, Challenges and Best Practices for Smart Energy Technology
14	2015	Chinese Taipei	China; Korea; Thailand; United States	EWG 23 2015A	Best Practices for Developing the Green Energy Smart Farm in the APEC Region
15		Chinese Taipei;United States		EWG 03 2015S	2015 Energy Smart Community Initiative (ESCI) Best Practices Awards Program
16	2016	Chinese Taipei;United States		EWG 04 2016S	2017 Energy Smart Communities Initiative (ESCI) Best Practices Awards Program
17	2017	Thailand	Chinese Taipei; United States; Japan; Philippines	EWG 11 2017A	Empowering a Distributed Energy Resource Future through Regulatory and Market Reforms
18		Australia	Philippines; New Zealand; Indonesia;Japan	EWG 13 2017A	Integrated Energy System Planning for Equitable Access to Sustainable Energy for Remote Communities in the APEC Regions using North Sulawesi as a Pilot Project/Test Bed
19		Chile	Japan; Mexico; Singapore; Chinese Taipei; United States	EWG 16 2018A	Distributed Energy Resources Regulation and Rate Design
20		China		EWG 03 2018S	Establishment of a Cloud-based Sharing Platform of Multi-Energy Microgrids for APEC Economies
21	2018	United States		EWG 09 2018S	APEC Energy Resilience Smart Grid Workshop
22		China		EWG 10 2018S	Research on Integrated Multi-Energy System to Improve Energy Efficiency and Enhance Technological Progress of Renewable Energy in APEC Region

²¹ APEC Project Database (PDB) (2019) APEC. <https://aimp2.apec.org/sites/PDB/default.aspx>

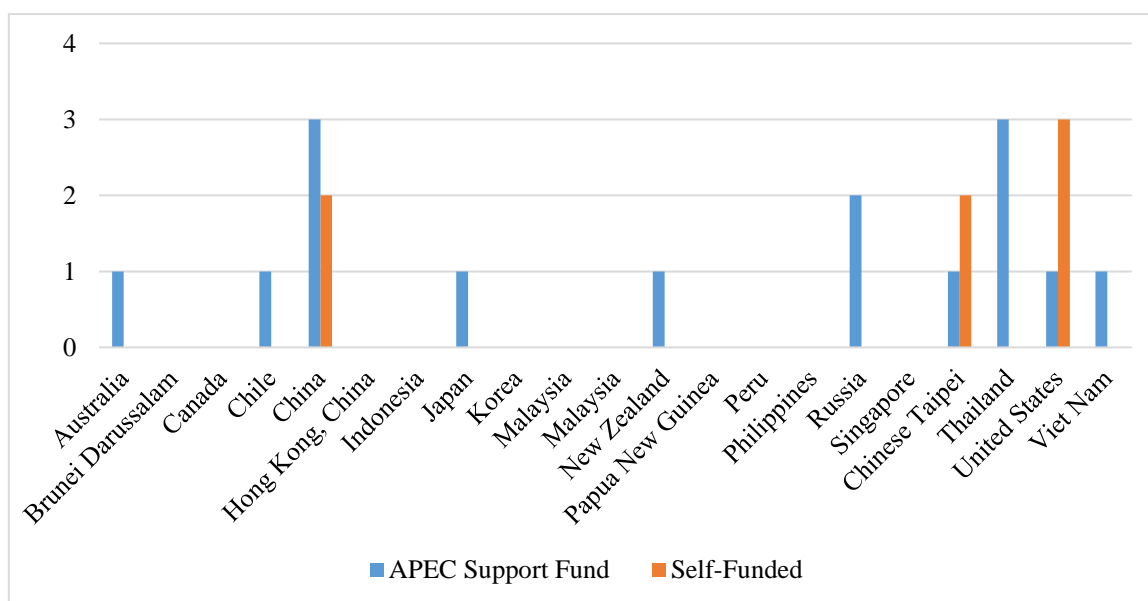


Fig. 1-3 Distribution of APEC projects in the field of integrated multi-energy

Table 1-4 Key words of APEC projects in the field of integrated multi-energy

Key Words	Project Numbers	Year / Proposing Economy(ies)
Smart	14	2018/United States; 2016/ Chinese Taipei & United States; 2015/ Chinese Taipei; 2015 Chinese Taipei & United States; 2014/Thailand; 2013/Thailand; 2013/China; 2012/Viet Nam; 2012/China; 2012/New Zealand; 2011/Russia; 2011/United States; 2011/China; 2009/United States;
Integrated Energy	3	2009/Japan; 2017/Australia; 2018/China
Distributed Energy	3	2012/ Russia; 2017/Thailand; 2018/Chile
Multi-Energy	2	2018/China

1.3 Application conditions of Integrated Multi-energy System

The implementation of integrated multi-energy should fully consider the resource condition of power supply side and energy using characteristics of load demand, and with this as the base, take the difference on generation, control, technological efficiency and environment into consideration, so as to suit the measures into local conditions and make integrated use. In this way, all types of energy will form a benign interaction while making up for each other's deficiencies. Thus, the disadvantage of singular energy supply will be compensated, and a cleaner, more efficient, safer and more reliable way of energy production and supply is promoted. The characteristics of various forms of energy are shown in Table 1-5. We can see that, renewable energy like wind power and PV are very different from hydropower and coal power in terms of using method, generating characteristics, energy density, reproducibility and stability.

Table 1-5 Comparison of main forms of energy

No.	Energy Form	Advantages	Disadvantages
1	Coal	Large distribution and reserve, mature technology; stable, controllable	Low thermal and burning efficiency, difficult exploitation, environmental pollution; high transportation cost
2	Petroleum	Easy exploitation, high calorific value, stable, and a wide range of application	High pollutant release after burning
3	Natural Gas	Relatively low pollutant release	Limited reserve, unequal distribution, high carbon emission
4	Hrdropower	Clean, renewable, low cost	Vary to the water yield (flood period, drought period)
5	PV/ CSP Technology	Clean, renewable, limitless reserve	Unstable, change with the light
6	Wind Power	Clean, renewable, limitless reserve	Unstable, fluctuate with the wind speed
7	Nuclear Energy	High energy density, small unit dosage of nuclear fuel	Outstanding disposal issue with nuclear safety and nuclear waste disposal
8	Geothermal Energy	Rich resource, and is suitable for direct use	Scattered, low energy density, difficult to exploit
9	Biomass Energy	Renewable, clean, rich raw material	Low energy density, have impact on crop farming on earth
10	Ocean Energy	Renewable, massive potential	Obvious geographic distribution, low energy density

Intergrated multi-energy involves reasonable selection, coordinated control and operational management on these forms of energy. It is a problem on optimization for multiple tasks and multi-constraint conditions, therefore in the application process; the conditions listed below should be highly focused:

(1) Resource endowment for satisfying energy form demand of intergrated multi-energy system.

Integrated multi-energy should fully consider the local resource endowment and suit into the local conditions. It also should reasonably adopt energy of various types to make mutual integrating combinations to meet the demand on power supply.

(2) The possibility for different energies to interconnect, integrate each other and mutually aid.

In integrated multi-energy, the energy forms at power source side are in some ways replaceable and convertible. If 2 forms of energy don't have the replacing possibility in technical perspective, the integrated multi-energy and mutual aid wouldn't be achieved.

(3) The load demand can be coordinatedly supplied by integrated multi-energy.

Implementing integrated multi-energy should be based on load demand. The load demand directly determines the energy consumption structure. The ratio and characteristics of industrial, residential and commercial energy use shall greatly differ from each other. Load demand for

electricity, heating and cooling at user sides changes with season and population movement. The integrated multi-energy can make coordinated supply in several operating mode.

(4) The implementation of relevant technologies that can support integrated multi-energy

Integrated multi-energy adds to the complexity of energy supply system. Due to the fact that the subsystems are closely coupled, issues like malfunction and disturbance can spread among the subsystems for a mutual impact. The technologies on energy system, which support the implementation of integrated multi-energy such as technical integration, operation control, dispatch management, information communication and data processing, guarantee the robustness and stability of the system.

(5) Operation service and business model can meet the requirement of integrated multi-energy operation.

In the integrated multi-energy, users can freely switch between several energy forms like petroleum, coal, natural gas and electricity. Traditional service provider of single form should turn into multi-energy ones. The operational model, market mechanism, supervising measures, business model and access conditions should all advance with the time to follow the development on the application of integrated multi-energy system. Otherwise it would not be friendly for the system implementation.

(6) Other conditions

Other application conditions of the integrated multi-energy include: policy, economy etc. The integrated multi-energy system should take governmental supporting policy, subsidy and financing support into consideration; economy is a critical condition that can determine whether the integrated multi-energy can be used for a long sustainable development. Low return on investment, low efficiency and deficit will severely affect the implementation of integrated multi-energy.

1.4 Main forms and typical models of Integrated Multi-energy System

1.4.1 Main Forms

(1) Seeing from the vertical energy supply chain of “source-grid-load”, the main forms of integrated multi-energy can be divided as the coordination complementation between concentrated resources near the power source side, and that between the distributed energy at user side. In this way, the horizontal mutual aid from “source” and “load” is achieved, and it

can make vertical synergy through the “source-grid-load” energy transmitting chain to create a high-efficient and stable integrated multi-energy system.

(2) Seeing from the space-time characteristic of energy, the main forms of intergrated multi-energy are geographicly regional energy complementation and timely contributing mutual aid. As the uneven distribution of natural resources in geographic areas, different energy forms in distinct regions can make up for each other. Meanwhile, on a timely basis, there lies the possibility for the energy forms to compensate mutually. For example, PV offers a bigger electric-power output during daytime with stronger sunlight, but at night the output is zero due to the absence of light. So we can use energy storage to compensate it by charging at daytime and discharging at night in order to equilibrate the fluctuation of PV power.

(3) Judging from the partition of renewable and non-renewable energy, the main forms of integrated multi-energy can be divided into 2 kinds as: the mutual aid of renewable resources, and the one between renewables and non-renewables. The mutual aid of renewable resources depends on the output characteristics of such energies like the capacity-featuring integration of wind power and PV; the integration between renewables and non-renewables is to use traditional stable energy as back-up power source to “optimize load shift” so as to achieve mutual aid like bundling delivery of wind and heating power.

(4) From the types of integrated energy, it can be divided into electricity mutual aid, heating mutual aid and chemical energy integration. Electricity integration refers to the integrated coordination of electricity power output which is generated by several generating units from primary energy source. Heating mutual aid means the integration between heating powers, for example, the integration between solar and coal heating. Chemical energy interaid mainly refers to the chemical compensations like hydrogen energy integration.

1.4.2 Typical models

There are 2 models in the integrated multi-energy system: one is the integrated multi-energy model at user side which faces end users demand on electricity, heating, cooling and gas etc.; the other one is integrated multi-energy model at power source side that aims for integrated energy base with resource combinations like wind power, solar energy, hydropower, coal and natural gas, as shown in Fig. 1-4.

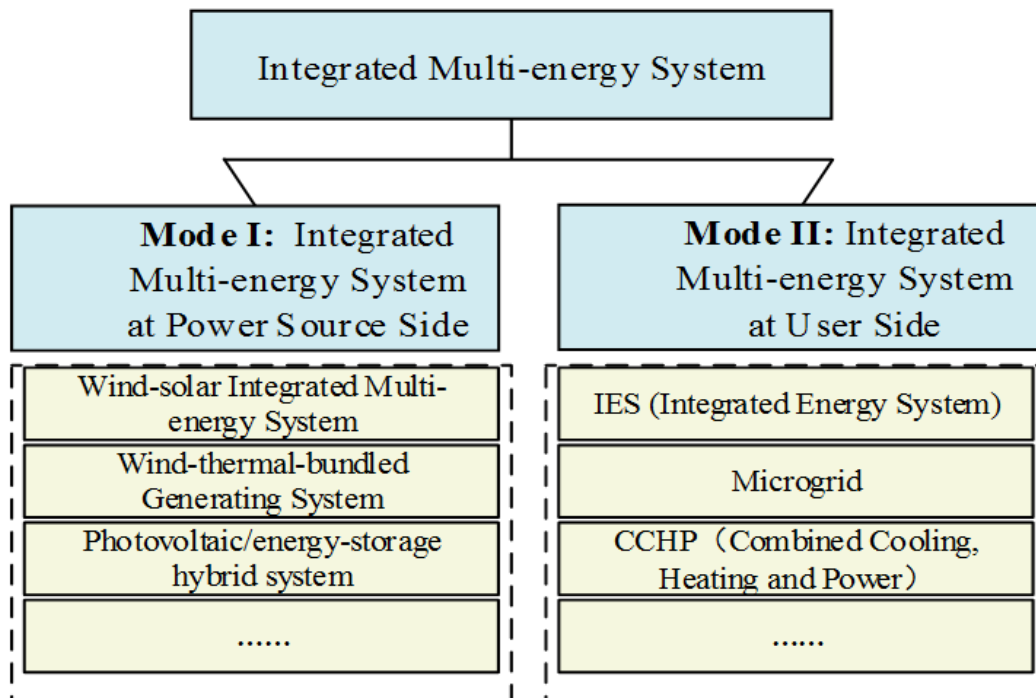


Fig. 1-4 Typical modes of Integrated Multi-energy System

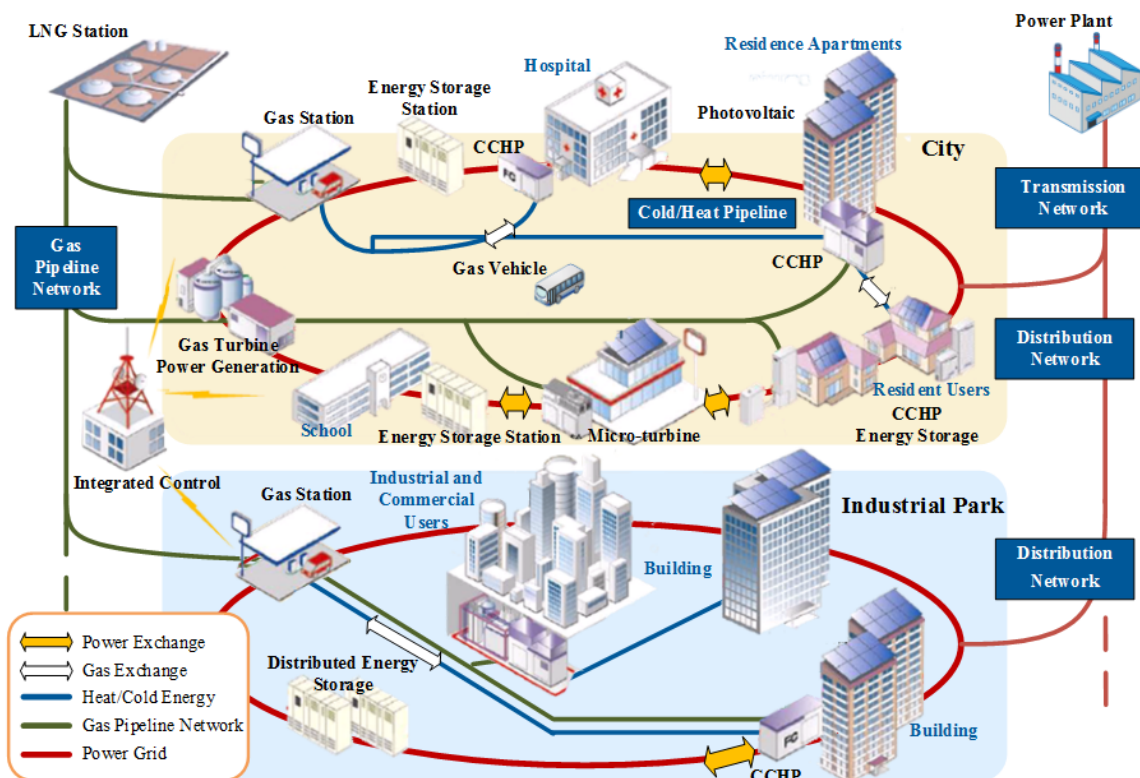


Fig. 1-5 Integrated Multi-energy System at User Side²²

²² Tokyo Gas. Challenge for the future society: smart energy network [EB/OL]. http://www.tokyo-gas.co.jp/techno/challenge/002_e.html.

(1) Integrated Multi-energy Model at User Side

Integrated multi-energy model at user side aims at facing the various energy demands from end users on electricity, heating, cooling and gas etc. It suits into the local conditions and make comprehensive use on traditional and new energy. The system builds up all-in-one integrated energy supply infrastructure with optimized distribution including implementing methods like natural gas distributed combined cooling, heating and power system (CCHP), distributed renewable energy and micro grid/micro energy networks etc.

The integrated multi-energy model at user side works in the way showing in Fig. 1-5. It achieves integrated multi-energy and coordinated supply to provide high efficient and smart energy supply and relevant value-added service. In the meantime, it implements energy demand management at user side, pushes the energy to be produced locally and digested nearby, improves energy comprehensive utilization rate.

(2) Integrated Multi-energy Model at Power Source Side

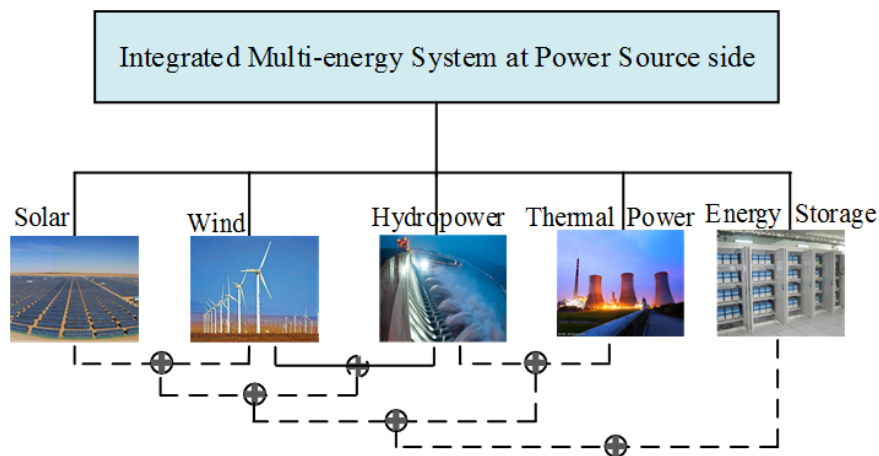


Fig.1-6 Integrated Multi-energy System at Power Source Side

The integrated multi-energy model at power source side (as shown in Fig. 1-6) refers to integrate the resource advantage of wind power, solar energy, hydropower, coal and natural gas for an all- in-one operation on the integrated multi-energy system of wind, solar, hydropower, thermal power and storage. In this way the stability of output power is improved, while at the same time, the capability and comprehensive effectiveness of the power system to digest intermittent renewable energy such as wind power and PV power etc is improved.

The model fully takes advantage on the flexibility of the hydropower generating units, the support and adjusting function of frequency to the basic load from thermal power units, on the fluctuating balance function of capacity-type energy storage, as well as on the energy

transforming ability of power-type energy storage. It eliminates the effect of uncertainty caused by wind and solar power to the biggest extent.

Per the regional characteristics where energy generating and consumption place are separated in natural resource enriched areas, the integrated multi-energy project at power source side needs to make centralized delivery through UHVAC transmission technology and UHVDC transmission technology. By superior combination of multi-energy system, the energy system stability and all-in-one optimized dispatch capability will be effectively improved so that the “wind power curtailment, solar power curtailment” and even “hydropower curtailment” are reduced.

1.5 Significance of developing Intergrated Multi-energy System

(1) Facilitate the digestion of renewable energy to realize the full coordination and sustainable development of energy and environment

Due the randomness and fluctuation feature of wind power and PV power, implementing a coordinating operation of wind power, PV power together with thermal power and hydropower will reduce the peak-shaving pressure of the power grid, and decrease the power control because of the wind power curtailment, solar power curtailment, hydropower curtailment. It also will effectively promote the digestion of renewable energy. By increasing the supply proportion of renewable energy, reducing consumption of fossil and cutting down carbon emission, the power grid can run safely, steadily and economically and the sustainable development of energy and environment will be achieved.

(2) Favorable for breaking barriers to achieve the united planning and integrated optimization

In the traditional energy supply system, the barriers between energy like petroleum, gas, electricity and hydro power are quite obvious. Therefore in the planning stage, they are generally separately planned, designed and operated and are lack of coordination. Issues were caused due to this fact, such as low energy utilization rate, poor general safety of energy supply system and weak capability of transaction supply and recovery triggered by malfunction.

In all aspects of integrated multi-energy such as power generation, transformation, storage and management, a systemized, integrated and careful method should be considered to be used for the analysis of the whole energy system. By such actions, the robustness and energy consumption efficiency of the whole system can be optimized so as to realize the uniformity and coordination on energy planning.

(3) Favorable for realizing gradient utilization and energy efficiency improvement

The gradient utilization can be achieved by the integrated multi-energy, and it will effectively transfer and use the power from fossil energy. It is an inevitable choice to enhance utilization ratio of the energy.

(4) Favorable for pushing the innovation and development of energy technology

Integrated multi-energy pushes the energy technology to be continuously innovated. The realization of integrated multi-energy has high requirements on technologies like energy storage, big volume energy transportation, energy replacement, transformation, energy internet, energy storage, response at user side, virtual power plant, cyber physical systems (CPS) and multi-energy flow scheduling and control etc. This situation makes it a hot technological topic for research nowadays. Many innovative results have emerged and they have greatly pushed the development of energy technologies.

(5) Solve the problem on power supply in areas without electricity

In undeveloped places such as agricultural and stock raising areas, remote regions and islands, the connection to the grand power grid is weak, whereas the power generation investment is big and the power is generally insufficient. The power grid even can't cover the whole area. Using the integrated multi-energy technology will create a regional energy system and use the local resources. By doing this, the generation, dispatch and utilization of the electricity in such region can be independent from the main grid and the cost will be reduced. This new local grid can also connect to existing grid to offer support and share load so problems like insufficient power supply and unstable voltage will be solved in these regions.

Chapter II: Introduction of Critical Technologies and Business Model of Integrated Multi-energy System

2.1 Technologies for renewable energy and energy storage

2.1.1 Technologies for the use of wind energy

The use of wind power is basically in two ways as: wind energy generation and heat generating by wind.

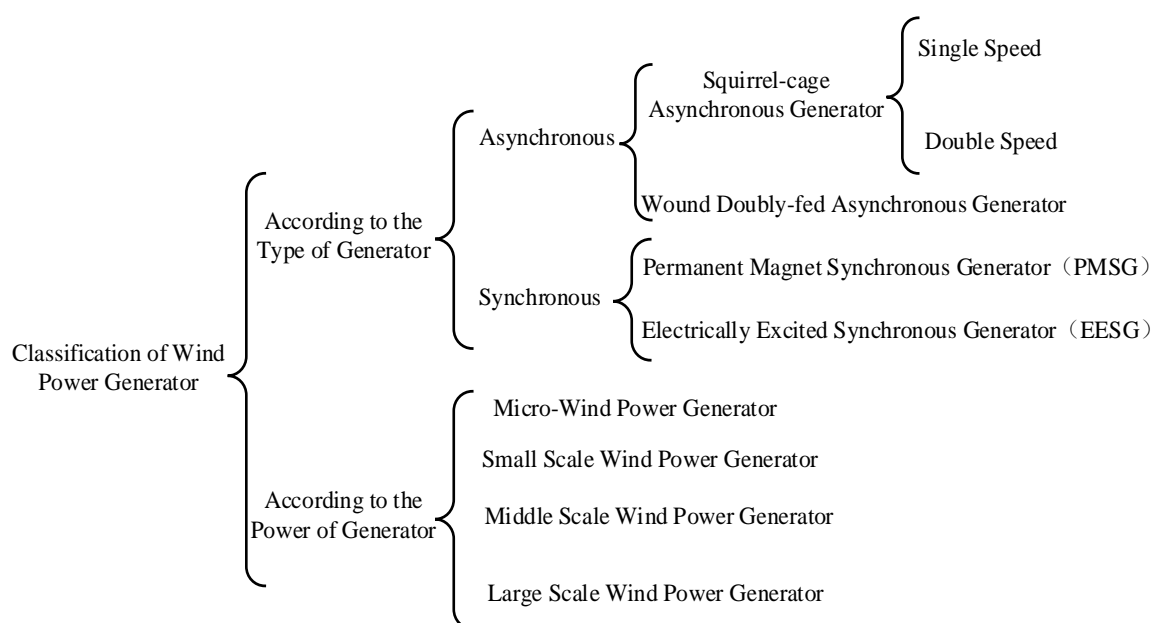


Fig. 2-1 Classification of wind power generator

Based on the installing model of rotor shaft on the wind-driven generator, such device can be divided into horizontal wind-driven generating unit and vertical wind-driven generating unit. Between the two types, horizontal wind-driven generating unit is most commonly used in the world. By the types of electric motor, the device is divided into asynchronized model and synchronized model. If divided by capacity, there are mini-sized, small sized, middle sized and big-sized wind-driven generators.

Wind power is a kind of energy with unstable fluctuation. Without energy storage device or integration from other generating units, the wind-driven generating unit itself can't provide stable power output. In order to make the grid contain certain percentage of renewable energy while maintaining the stable operation of the power grid, on one hand, the grid needs to add construction on pumped storage station and quick-start gas power station; on the other hand, wind farms should equip local energy storage device while increasing power unit control in

order to satisfy the requirement on stability and safety for power grid during the regular running (normal state, malfunction, temporary status, in-operation status).

- **On-shore wind energy technology**

On-shore wind energy mainly refers to construct and operate wind generating units on land in the relatively enriched area of wind resource. On-shore wind energy technology is one of the early developed techniques so it's quite mature. The capacity of a single wind energy generator increases from kW level to MW level, which is 100 times more. The biggest wind energy generator has reached over 6MW. At present, on-shore wind energy technology now fastly develops toward the trends including: increasing the volume of single wind energy generator, promoting the wind catching for the turbines, enhancing transforming efficiency of wind energy, and reinforcing environmental compatibility for the generators.

- **Off-shore wind energy technology**

Comparing on-shore wind energy technology, off-shore wind energy technology is a critical developing direction for the wind energy generation in recent years. Off-shore wind energy technology refers to the the wind energy generators that are built and operated in the coastal areas or around the islands.

The operation environment of off-shore wind energy technology is very complicated and more difficult to construct and build. It also has a rather high maintenance cost. But off-shore wind energy is with richer wind resource, bigger generating capacity and longer annual operation time. In Table 2-1, we can see the function comparison of off-shore and on-shore wind energy.

Table 2-1 Function comparison of off-shore and on-shore wind energy

Characteristics	Off-shore Wind Energy	On-shore Wind Energy
Quality of Wind Energy	Low cut-in wind speed, stable	High cut-in wind speed
Volume of Single Unit	Big	Small
Annual Using Hours	3000	2000
Operation Life	25 years	20 years

- **Technology for heat generated by wind energy**

Technology for heating generated by wind energy is a technical way to turn wind energy into heat. Wind energy is mainly a mechanical energy. Besides pushing generators to generate power, another common measure to use mechanical energy is to make heat. Currently, there are 3 types of technology for heating generated by wind energy:

(1) Heat from electricity generating by wind

The technology uses the electricity generated by wind energy to generate heat by heating equipment with wire spiral, and then collects heating energy; or generates heat with the eddy current created by putting magnetizing coil between outer edge of the rotator and stator.

(2) Heat from wind turbine stirring

Heat can be generated from liquid stirring driven by wind energy. The rotation shaft of the wind generator stirs the liquid in the container so a vortex is formed. This vortex can gradually heat up the liquid in order to acquire heating energy. Such heat generated by stirring is generally of a high efficiency.

(3) Heat from air-compressing by wind energy

Heat from air-compressing by wind energy is to use the wind generator to lead the centrifugal compressor and make an adiabatic compression from the air. This way of air compression will generate some heating energy in the process, and mechanical energy stored from compressed air can be transfer into heating energy.

2.1.2 Technologies for the use of solar energy

Technologies for the use of solar energy mainly include: generating techniques by solar energy (contain PV solar power technology and concentrating solar power technology), and direct heat-using solar energy technology.

PV power generation is to create electricity by the energy of sunlight. PV solar power technology means the photocells, making by semiconductor materials, takes advantage of photoeffect to directly turn solar power into electricity.

● Centralized PV solar power technology

Centralized massive grid-combining PV solar power technology is a technical method to set up PV device in sunlight-enriching areas to form a centralized power station then connect it to the power grid for power supply. The general volume and covered area for centralized PV power station are relatively big, so the technology can be built in remote and empty locations with very small population. A PV power station needs professional people to maintain and be stationed and it's with more additional devices. In general, centralized PV technology has better stability and more flexible operation mode. This will facilitate the centralized dispatch and uniform management. It also can reinforce the regulation related to the power grid and it's easier to form scale effect with this technology.

Ground PV power station of big and medium size is generally composed of PV solar energy module array, PV rectifier/contravariant system, grid integration system and secondary control system etc. As centralized PV power stations are always built in regions like desert, the Gobi and far from center of load, it often requires a high-voltage transmission system to deliver electricity.

- **Distributed PV power technology**

Distributed PV power technology mainly refers to the PV power generating device that constructs and runs near the users' location. It mainly depends on self-generating and self-using on user side, and only the extra power will be deliver to the grid.

Distributed PV power technology usually installed on the locations like users' stairs, roof of house or workshop and vegetable greenhouse which can make full use of various space. Its prominent feature is, due to the geographical dispersibility, the installing locations are with smaller size and more flexible comparing with centralized PV power technology. The advantage and disadvantage of both technologies are shown in Table 2-2.

Table 2-2 Advantage and disadvantage comparison between centralized and distributed PV

PV Power-generating Mode	Advantages	Disadvantages
Centralized PV solar power technology	Quite stable output and has certain integration effect; controllable operation mode and easy for idle/voltage control; low running cost and easy for uniform management and adjustment.	Requires long-distance transmission so has stronger impact on power grid; PV array requires capability on centralized control and low voltage ride through
Distributed PV power technology	Close to user side and easy for nearby digestion. Low line loss so can effectively use various spaces on construction, workshop and vacancy area.	Random switch-in can lead to change on electric network tide and have impact on existing protection configuration and reliability. Difficult maintenance and overhaul.

- **Concentrating solar power (CSP) technology**

Concentrating solar power (CSP) technology uses solar energy as the heat source for the power generation system. It aggregates low-density solar energy into high-density one through condenser and then turns solar energy into heating energy with heat-transfer agent, and finally realizes the transformation to electric energy by cyclical heat work. The main forms include: parabolic trough CSP technology, central tower CSP technology and parabolic dish CSP technology.

Specific technical comparisons are shown as Table 2-3.

Table 2-3 Comparison on Ttechnical Features of three typical CSP Technologies

Type	System Composition	Technological Features
Parabolic Trough CSP Technology	Composed of optical collector, absorber pipe and thermal storage device	By serie or parallel connection of several optical collectiong and heat absorbing device, it forms a CSP power generating system of a quite big volume, long circuit on thermal transmission and big heat loss. The comprehensive capacity of the system is low, about 11%-15%, but with a simple structure and low cost.
Central Tower CSP Technology	Composed of subsystems like CPV, heat integration, heat accumulation and power generation	The technolocy allows various solar reflectors on a big area so the absorbed solar energy can be turned into heat energy. The comprehensive capacity of the system is about 15%-35%. And with low technical risk.
Parabolic Dish CSP Technology	Composed of optical collector of parabolic dish, Stirling engines and transmission system	By accumulating the sunlight shines one the parabolic surface onto the focus, the stirling engines will be pushed to reciprocate. In this way, the heat energy will be converted to mechanical energy and then drive the generator to create electric energy. The comprehensive capacity of the system is about 12%-25%. No need for heat storage or water consumption but the investing cost for the device is quite high.

● **Direct heat-using solar energy technology**

Sunlight can be converted directly into thermal energy through plate collectors and heat bumps etc, as shown in Table 2-4. Common ways to take advantage of solar heat includes: solar water heater, solar heating, solar heat pump and solar air collectors etc.

Table 2-4 Typical ways for direct solar heating

Typical Ways for Solar Heating	Application
Solar Water Heater	Provide daily and manufacturing hot water
Solar Heating	Living heating
Solar Cooker	Provide heating, food cooking
Solar Heat Pump	Provide heating
Solar Air Collector	Provide heating, hot water and hot gas

2.1.3 Technologies for use of hydro energy

● **Hydropower generating technology**

Hydropower generation is to collect the potential energy creating by the water from rivers and lakes to flow from high to low locations. The primary energy source of hydropower is water pontetial energy. The basic principle is taking advantage of the drop height of the water

level, and transforming the potential energy into kinetic energy of water turbine, then using the water turbine as the motive power to coordinate with hydrogenerator to create electric energy.

Hydropower generating can be divided into following types per the way to accumulate drop height: dam-type hydropower plant, diversion hydropower plant, mixed hydropower plant, tidal hydropower plant and pumped storage hydropower plant. If dividing by the scale of streamflow regulation, the main types are: unadjusted hydropower plant and adjusted hydropower plant. For hydropower generating, the characteristics are: high efficiency, low cost, instant start units and easy adjustment.

A hydropower station generally runs in a long term with the water storage and drainage of the reservoir, so its function approximately can be divided into flood season and drought season. It operates along with the change of the streamflow. As the distribution of water season differs from each other, for reservoirs with capability of periodical adjustment or the ones mentioned above, it can basically use the adjusting ability to arrange the annual operation plan for the station in order to achieve the re-dispatch on feedwater in different seasons with the purpose of maximizing power output.

● **Pumped storage technology**

Pumped storage uses the electric power during low load period of the grid to draw water from lower reservoir to head one for power storage, and then release the water back to the lower reservoir for power generation. A pumped storage station is to change the electric power in low valley to peak load period. It doesn't generate power but re-dispatch power in the grid on a timely basis. In the load valley, the technology uses spare electric power to pump the water from lower reservoir to head reservoir and store energy in the form of water potential power. Then in the peak load, it releases the water from head reservoir to low reservoir through water turbine. The potential energy of the water is then transformed into electric power back to the grid. Like this, one circle is completed: water level of head reservoir changes from lowest of power generation to normal impounded level, then back to the lowest for power generation; while the water level of lower reservoir turns from normal impounded level to lowest for power generation, then rise back to normal impounded level from there.

Pumped storage is very suitable for peak-shaving in the power system or working as a back-up power source. The releasing time for stored energy can range from a couple of hours to several days, and the efficiency is between 70%-85%. The main application fields are: energy management, frequency control and system back-up power supply. Its main characteristics are as follows:

(1) Pumped storage power station has a quick start and stop, and fast switch on operation mode as well as supercharging and deloading. Also its operation is flexible and reliable with a low outage rate, strong load following capability. It's suitable for frequency change for power system, emergency back-up and load back-up therefore it's an excellent spinning back-up power source. Pumped storage stations that are close to the load central areas can make phase modulation, balance reactive-power, stabilize regional voltage and improve the reliability of the power grid.

(2) Pumped storage power stations not only can work under the operation mode of water turbine, but also can work in water pump operation mode. It can generate electric power, and can provide the power grid with electricity as well as absorbing the electric power from the grid. It is a power generating source, and also an electricity load. It can increase power supply while improving the rate of loading for the power grid. Pumped storage stations that are close the load central areas can adjust reactive-power under water pumping and power generating operation mode. It can transmit reactive power to the grid, while absorbing the grid's reactive-power. It adjusts the reactive-power of the grid in both ways, stabilizes the voltage of the power supply areas and increases the stability of the grid's operation.

(3) Hydropower storage is one of the most mature technologies and the energy storage technology with biggest device volume at present. The maximum volume has reached more than 1GW. Hydropower storage requires special topographical conditions where head reservoir can be built therefore the one-time investment is big but the operation life is long. Pumped storage has the same merit of flexible start-stop as the regular hydropower stations, and can effectively stabilize the short and random fluctuation caused by wind power and PV power.

Due to these special advantages, pumped storage station can implement functions in the power system like: peak-shaving, frequency change, phase modulation and spinning reserve etc. It increases safety and economy of the grid operation. Restricted by natural conditions, wind power and solar energy shows characteristics such as stochastic fluctuation and intermittency so can't meet users' requirement. Pumped storage station has the function to store energy, and fast start-stop. It can not only serve as an energy storage device to effectively solve the electric power problem on surplus and deficiency during operation caused by intermittent energy, but also can used as an instant-adjusting power source to level off the output capacity of wind and PV energy in order to reduce the effect on the grid from fluctuation. The integrated operation theory of pumped storage stations and renewable energy power generation works as shown in Fig. 2-2. The joint integrated system uses the energy storage advantages of the pumped storage station like fast start-stop, flexible operation and energy storage to improve

the power generation utilization, and reduce negative impact from fluctuating renewable energy to the power grid.

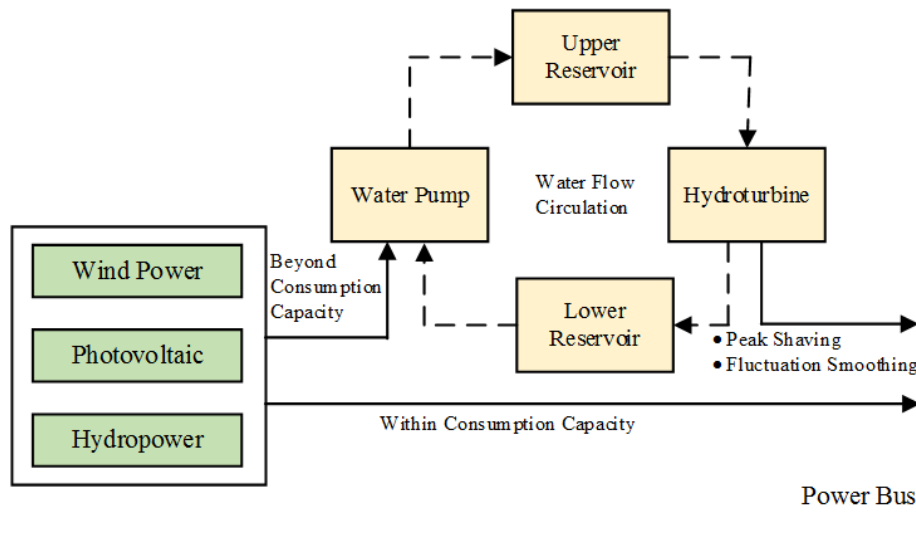


Fig. 2-2 Pumped storage combined with renewable energy

2.1.4 Technologies for the use of biomass

Besides direct burning, the technologies for the use of biomass mainly include:

(1) **Biogas made of biomass.** It mainly uses biomass like organic garbage, straws, water, human and animal faeces to turn into methane with the effect of facultative anaerobe and obligate anaerobe to provide methane for living and production use.

(2) **Ethanol made by biomass.** The technology mainly takes advantage of cellulose, hemicellulose, lignin and sugar containing in the biomass, then uses microbial fermentation technology to create ethanol that can replace petroleum in certain scale for use.

In the field of biomass power generation, the main using measures includes biomass power generation by agriculture and forestry, by municipal solid waste (MSW) incineration and by biogas.

In recent years, the coupling integration of coal firing and biomass achieved a fast development. Biomass, as a fuel to coupled integrating with coal, can create an integrated power generation system. The implementations mainly include 3 types as shown in Fig. 2-3.

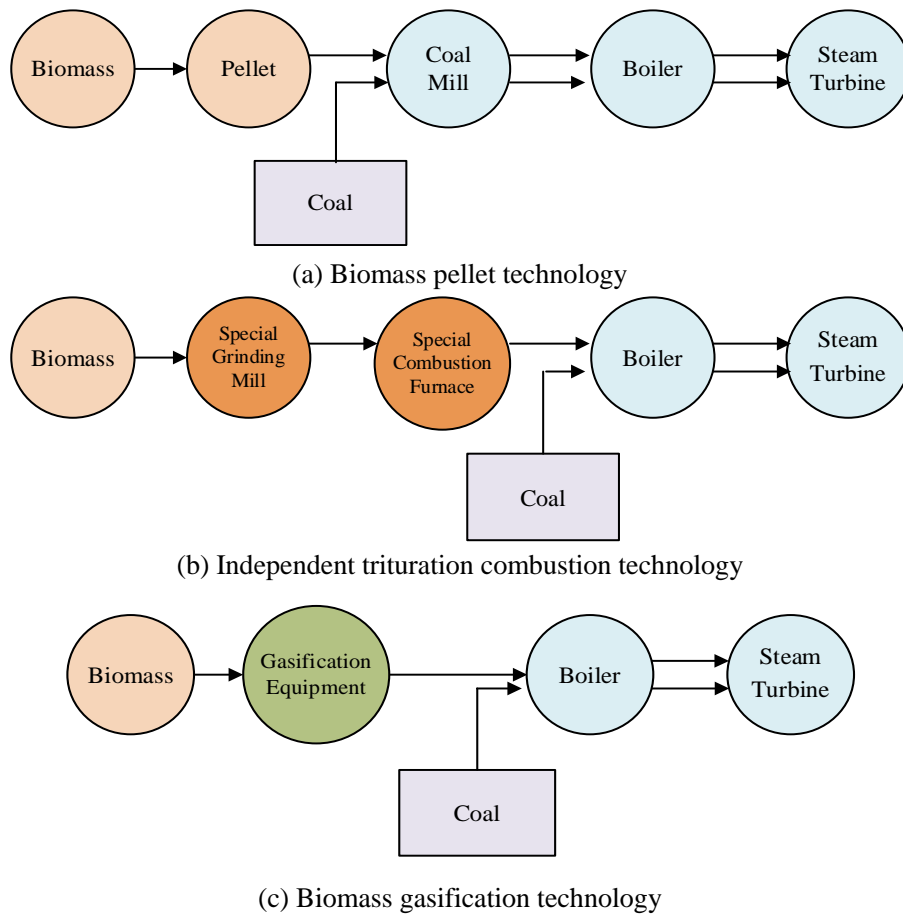


Fig.2-3 Biomass-coal coupling power generation system

(1) Biomass pellet forming technology: process biomass materials such as straws, rice grass, rice husk, peanut rusk, corn cob, camellia shell and cottonseed hull to form pellets of 6-10mm, and then mix it with coal to put into the pulverizer. Later all will be put into the furnace for power generation.

(2) Independent breaking burning technology: this technology is to put biomass pellet into special combustor then mix it with coal in the furnace system for coupling so as to achieve an integrated power generation.

(3) Biomass gasification technology: it is a kind of technology where biomass will be effectively gasified in cyclical fluidized bed gasificator and generates gas for dust removal in the purification system. The the gas will go directly into a large coal-fired utility boiler in the form of hot gas, and is mixed with pulverized coal for burning. The technology is a highly effective power generation way which also combines with the original power generation system.

2.1.5 Energy storage technologies

Energy storage is an important composition and supportive technology for smart grid, energy system with high proportion of renewable energy, “internet+” intelligent energy. Energy storage can offer the power grid with various services like peak-shaving, frequency change, back-up, black-start, demand response etc. It is an important measure to improve the flexibility, economy and safety of traditional power grid, and also a critical technology for improving digestion level for renewable energy, supporting operation of distributed power generation and microgrid. It also is a key technology for pushing the development of renewable energy. Table 2-5 is a function comparison of main energy storage forms, and analysis on the applicability.

Table 2-5 Function comparison of main energy storage forms

Type of Energy Storage	Energy Density (W·h·L ⁻¹)	Capacity Density (W·L ⁻¹)	Reaction Time	Applicability
Supercapacitor	10~20	4000~12000	ms~15min	Smooth load, supplement for voltage, black-start support
Flywheel Energy Storage	20~80	5000	15s~15min	Peak-shaving, frequency control, UPS, power quality control
Superconducting Magnetic Energy Storage	0.2~1.5	1000~4000	ms~15min	Smooth voltality, system reserve capacity, system voltage support
Pumped Storage	0.2~2	0.1~0.2	4h~10h	Energy management, frequency control and system back-up
Compressed Air	2~6	0.2~0.6	6h~20h	Peak-shaving power plant, system back-up power source
Lithium Battery	200~400	1300~10000	1min~10h	Smooth voltality, back-up power source, voltage/frequency control, peak load shaving
Lead-acid Battery	50~80	90~700	1min~3h	Smooth voltality, power quality control, system back-up power source, black-start, UPS
Sodium-sulfur Battery	150~300	120~160	1min~1h	Smooth voltality, system back-up power source
Hydrogen Energy	600	0.2~2	1s~10h	Peak-shaving, stabilize fluctuation

● Electricity storage technologies

In a power system, energy storage technology covers all links from power generation, transmission, transformation, and dispatch to consumption, and it plays an important supplementary role in different typical scenarios. Energy storage mainly solves the problem of the storage on electricity quantity. Energy storage system can ease the supply and demand conflict in a certain scale to deal with the electricity need in peak load. It also can improve the utilization ratio of the grid device and the operation efficiency of the grid so as to achieve a more flexible energy and resource distribution. Energy storage technology can be applied to power generation of renewable energy, can balance the randomness and intermittent capacity

fluctuation in the power generation caused by renewable energy like wind power and PV therefore improve the digestion of renewable energy.

Based on the responding characteristic of charging and discharging time, energy storage system can be divided into energy storage system of efficiency type, and that of power type. Typical technologies in the energy storage system of efficiency type include: supercapacitor and flywheel energy storage. The advantages of this type are quick reponse, long circulating life-span and small volume etc. So it's suitable to make up of short power fluctuation; energy storage system of power type mainly includes: storage battery, pumped storage and compressed air. The advantages of this type are: big volume and slow response therefore it's suitable for complement long power fluctuation.

(1) Supercapacitor

It's developed based on double layer theory from electrochemistry so it's also called double layer capacitor. The distance between the 2 charging layers are very small: generally smaller than 0.5mm. It uses special electrode structure to increase surface area of electrode in tens of thousand times in order to create a massive electric capacity.

(2) Flywheel energy storage

The grid provides flywheel energy storage with electric power. The technology uses electric motor to drive the flywheel to spin in very high speed, and stores the electric energy in the form of kinetic energy initiated from the flywheel. When power supply is needed, the flywheel will serve as prime mover to drag the generator for power generation and export to the electric consumers. The flywheel energy storage system is mainly composed of 4 parts: rotator, electric motor/generator, power converter and vacuum chamber. In order to cut down loss, modern flywheel energy storage system is normally made up of a cylindrical spinning mass block and a mechanism supported by magnetic bearing. Flywheel energy storage is commonly used in industry and uninterruptible power system (UPS). It applied for frequency regulation in the operation of power distribution system. It can also be used as a UPS without storage battery to quickly switch power source, maintain the short-time frequency stability of the small system when the electric power supply is malfunctioned in order to guarantee the power supply is uninterrupted, and restrain voltage fluctuation/dip.

(3) Superconducting magnetic energy storage

Superconducting magnetic energy storage system is to use superconducting magnet with zero resistance to form a superconducting coil so as to create an inductance which will create

magnetic fields around the coil after charging with electricity. In this way, the electric power will be kept in the system in the form of magnetic energy. When needed, the stored energy can be transmitted back to the power grid for other applications by inverters. The system device of superconducting magnetic energy storage mainly includes 4 parts: superconducting coil and cryogenic vessel, refrigerating installation, converter plant and measurement & control system. The superconducting magnetic energy storage is with more times of charge-discharge, longer life-span, higher efficiency on charge-discharge, faster speed and responding time, as well as a convenient control, high power density. It's also environmental protective with no pollution, and has no construction limit on location. But the system is with limited energy storage volume, high building and maintenance cost. There is also a safety and reliability issue when the superconductor is quenched.

(4) Pumped storage

Pumped storage power station is a way to store energy that is created to solve the supply-demand conflict during the peak load and load valley of a grid. Pumped storage is equipped with 2 reservoirs: head one and lower one. In the load valley, the pumps in the system use the electric energy to draw water from lower reservoir to the head one for storage; in peak load, the water in the head reservoir is released back to the lower reservoir and using electric motor to generate power, then the electric power is transmitted into the power grid to complement the power needed in peak period. Like this the power generation pressure of the power plant will be reduced. The system achieves load shifting by consuming in load valley while generating in peak load. Pumped storage power station mainly serves in the power grid for peak-shaving, frequency change, phase modulation and emergency back-up.

(5) Lithium battery/Lead-acid battery/Sodium-sulfur battery etc.

Lithium ion battery is a kind of secondary battery that uses lithium-containing compounds as positive electrode, and achieves charge-discharge by reciprocating and embedding of lithium ions between the positive and negative electrodes of the battery. Lithium ion battery is actually a type of concentration cell with lithium ions. During charging, lithium ions are formed at the positive electrode and they move across the electrolyte to the negative electrode and embedded into the micro pore in the materials of negative electrode; in the discharge, the lithium ions will embed in the negative electrode disengage and move back to positive electrode.

Lead-acid battery is a kind of storage battery of which the electrodes are made of lead and its oxides, and the battery's electrolyte is made of sulphuric acid solution. In the state of charge,

the main content of positive electrode is lead dioxide, and that of negative electrode is lead. In the state of discharge, the main content of both electrodes is lead sulfate.

Sodium-sulfur battery is a type of secondary battery that uses sodium as negative electrode, sulfur as positive electrode, and ceramic tube as electrolyte membrane. In certain workability, the sodium ion produces a reversible reaction with the sulfur through electrolyte membrane, and in this way energy is released and stored.

- **Gas storage technologies**

For gas storage technology, here mainly introduces energy storage with compressed air and hydrogen-storing technology.

(1) Energy storage with compressed air

Energy storage with compressed air is an energy storage system mainly based on combustion turbine. In off-peak period, the system uses electric energy to compress air and store it in the subterranean caves or container under the sea (like abandoned mines, gas tank subsided in the bottom of the sea, cave, expired oil-gas well or newly-built gas storage well); in peak period, the system releases highly-compressed air from the gas storage room and mixes the air with fuel into the combustor of combustion turbine to burn in order to drive the combustion turbine to generate power. The energy storage theory is mainly to save power output of turbine consumption by compressing air without gas compressor. Thus, the energy which was planned to be used for compressors to compress air will be stored. Therefore, comparing with the combustion turbine system that consumes same fuel, the compressed air energy storage system can generate at least one time of the electric power.

(2) Hydrogen storage technology

As a clean fuel, hydrogen has a high calorific value. Its combustion product is water so wouldn't release greenhouse gas to the environment; therefore it's an ideal secondary energy. Converting the wind and solar power which are commonly curtailed because of the insufficient digestion into the hydrogen for utility is a solution that is technically practicable and economical. The integrated multi-energy model using hydrogen as the core is shown as Fig. 2-4. It achieves energy in different forms such as: use solar and wind power to hydrolyze and get hydrogen, ferment biomass to make hydrogen and use PV power to hydrolyze and get hydrogen etc. In this way, energy is transformed into homogeneous hydrogen, and by storing and transmitting hydrogen to end users for application.

Currently, hydrogen-making technology mainly includes following types:

Hydrogen-manufacturing from fossil fuel or hydrogen-rich gas: such as hydrogen-manufacturing from natural gas. Under the function of certain pressure, high temperature and catalyst actions, alkane from natural gas set off a chemical reaction with water vapour and turn into H₂ and CO₂. Then through heat transfer, condensation and steam-water separation, hydrogen can be extracted.

Hydrogen production by hydrolysis: it mainly refers to water electrolysis, alkaline electrolysis, membrane electrolysis of polyelectrolytes, high-temperature electrolysis, photoelectrolysis, biophotolysis and thermochemical hydrolysis. Such as using electric energy generated by solar and wind power to electrolyze in electrolytic bath full of electrolyte to form big quantity of hydrogen.

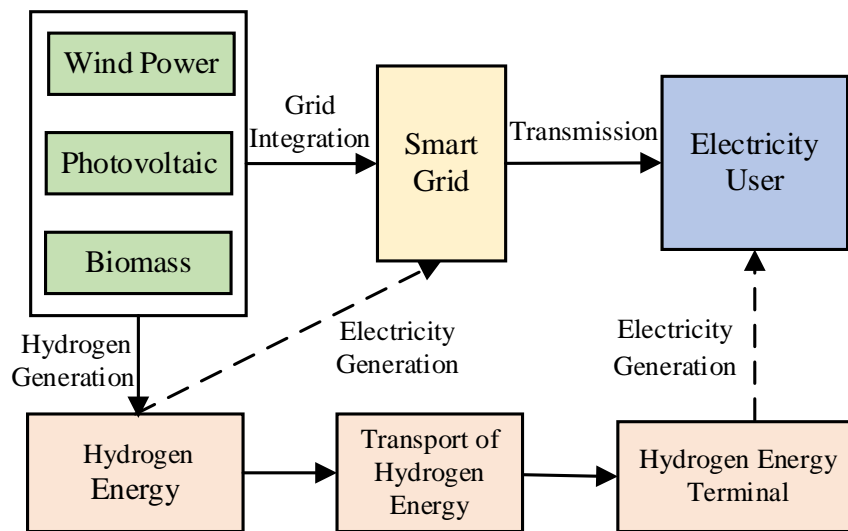


Fig. 2-4 Integration of hydrogen energy with renewable energy

- **Heat storage technologies**

Heat storage is a very important way for energy storage. High-temperature heat storage technology is widely used in solar-thermal power generation, balancing output instability caused by unsteady lighting condition, improving the dispatching capability of CSP power stations. Installing massive heat storage can increase the generating hour for power stations, or even realize a 24-hour power generation for CSP power stations to improve the economic income of the stations. At present, there are 3 types of heat storage technology: sensible heat storage, phase transformation storage and chemical reaction storage.

(1) Sensible heat storage

Sensible heat storage is a heat storage mode that takes advantage of internal thermal capacity of the materials. Currently the main heat storing materials for sensible heat storage

are the ones with big thermal capacity such as siliceous, refractory brick of magnesium, iron trioxide, cast steel and iron, water, heat-conducting oil and sandstones. Among the mentioned materials, water has a big specific heat, and low cost, so it is mainly used in low-temperature heat storage; heat-conducting oil and nitrate has a high boiling point, so can be used for solar medium-temperature heat storage.

(2) Phase transformation storage

Phase transformation is happening when the materials absorb or release a bit amount of latent heat during the change of state. Normally based on different forms and temperatures of the phase transformation, the energy storage materials can be classified in a more specific way. Per different forms of phase transformation, materials of phase transformation can be divided as solid-solid phase transformation, solid-liquid phase transformation, solid-gas phase transformation and liquid-gas phase transformation. Dividing by different temperature ranges of the phase transformation, the materials can be categorized as high-temperature, medium-temperature and low temperature ones. There is not a clear boundary between the different temperature ranges so sometimes a large scale of temperature overlapping is commonly seen. But in practical use, the heat source that needed to be stored has a certain temperature envelope, therefore it's more practical to categorize by the temperature of the phase transformation. Normally, 120°C and 400°C are set as the low, medium and high temperature point for the energy storage material of phase transformation.

(3) Chemical reaction storage

Chemical reaction storage is to use reversible chemical reaction and store energy by the transformation of heat energy and chemical heat. There are more than 70 kinds of thermal chemical reaction have been studied, but not much reaction systems are ideal. Typical energy storage technologies by thermal chemical reaction include: decomposition of inorganic hydroxide, ammonia decomposition, carbonation decomposition, catalytic reforming of methane-carbon dioxide, thermal decomposition of ammonium salt, hydrogenation and dehydrogenation of organic matters etc. The main advantages of energy storage by thermal chemical reaction are: big heat storage capacity, wide range of using temperature range, no need for isolate heat storage tanks. What's more, if catalyst or reactant is used during the reaction process, heat energy can be stored for a long time so the technology is very suitable for storing solar energy in the CSP process.

2.2 Integration technologies of Integrated Multi-energy System

The integration technologies of integrated multi-energy system mainly involves model choosing, distributing planning of various energies' volume, operational control technology and power dispatch technology etc.

2.2.1 Integration model of Integrated Multi-energy System

The integration of integrated multi-energy is based on the full use of features of all kinds of energy forms to create an optimized portfolio in order to reach the optimizing goal.

From the characteristics of natural resources, wind and solar energy is random but in some ways integrated. For example, solar energy is strong enough in daytime, and wind energy is rather weak; during night, solar energy is basically zero, but intensity of wind energy will increase. So these two have integrating effect in certain scale. Another example is that for wind and hydro energy, wind energy is abundant in winter and spring yet hydro energy is in short due to drought season; in summer and autumn, hydro energy is rather rich while wind energy is poor. Wind and hydro energy can achieve integrated output too. Therefore, considering the characteristics of geographical distribution and time, multiple energies can construct a unified integration, and by a centralized operation control, the stability and sustainability of system output can be improved.

Regarding the adjusting characteristics, the power output of wind and solar energy is mainly related to ambient temperature, solar radiation and climate change. So it shows an obvious daily and seasonal cyclical feature, and is always with strong intermittency and fluctuation and poor control. Hydro power and regular thermal power on the other hand is often with strong controllability. The adjustment on reservoir capacity of hydro energy allows a free regulation in certain scope, and therefore not totally affected by natural precipitation and channel flow. Regular thermal power is totally controllable so it can be used as a frequency change and peak-shaving power plant to stabilize voltage and frequency. As a result, power source with strong fluctuation is a good compensation for controllable ones.

At the same time, the development of all kinds of technologies on gas, electricity and heat storage offers more effective measures for integration of different energy forms. All types of energy can take advantage of transforming means, firstly convert into forms such as gas, electricity and heat etc., and then make integrated output. Like this the essential difference of these energies can be eliminated and achieve an integrated combination.

Currently, the integrations model of various energy forms are basically divided into the following three types:

(1) The integration model of electric powers

The integration model between electric energies is a model that uses electric power as the core. In this model, all energies are used for generate electric power and ensure the output stability by the integrated control strategy at electric energy side. Like this the general controllability of external electric power output is achieved. Common examples of this model are wind-PV storage cogeneration, wind-thermal bundling generation and micro grid etc.

(2) The integration model of electric-thermal energies

The integration model of electric-thermal energies is the model that fully uses heat energy for integration. This model can transform many kinds of electric power from renewable energy into heat, and then achieve integration by the direct or indirect use of the heat. Common applications of this model include: coupling generation model of biomass and coal, cogeneration model of solar-PV-thermal power, distributed combined cooling, heating and power system.

(3) The integration model of electric-chemical energies

The integration model of electric-chemical energies is the model tha uses chemical energy as integration agent. This model fully uses the process where renewable resource can be converted into chemical energy, and then transforms to electric energy or thermal energy. Common practices of this model are: hydrogen/gas/ethanol making by renewable resources, fuel cell etc.

2.2.2 Capacity planning technology of Integrated Multi-energy System

The capacity planning for integrated multi-energy system is an optimized planning solution for keeping the electric quantity balance. The total installed capacity of the system is composed of hydroelectric capacity and the credible capacity of wind and solar energy. The planning objectives can be: lowest system construction investment, lowest expected value on undersupply and maximum margin on system stability; conditions of constraint are: equilibrium constraints on electric quantity, wind/solar/hydro output constraint and unit start-stop constraint etc.

Capacity planning technology of integrated multi-energy system is not only affected by the operation and adjustment capability of traditional units, but also should consider load status, grid structure and acceptable capacity.

(1) Load characteristic of power supply areas: it mainly refers to the load requirement on power quality, the function curve of the load that changes along with the load and frequency etc, of which the load requirements on electric quality, power supply reliability will be the biggest measuring factor to restrict the maximum penetration rate of the renewable resources with fluctuation.

(2) Adjusting capability of traditional generating unit on the system: the adjusting capability of thermal power unit mainly refers to the capacity using for spinning back-up, gradeability of thermal power unit, and adjusting ability on voltage and frequency etc. The thermal power unit takes on functions in the system like base load, voltage adjustment and frequency change. Due to the uncertainty of the renewable energies, the proportion of thermal power unit should be increased in order to improve its adjusting capability on voltage and frequency. In this way, supports will be switched in for the renewable energies with higher penetration rate. Table 2-6 is the gradeability comparison of coal, natural gas and hydropower generating units. In the Table we can see that natural gas and hydropower generating units are with stronger gradeability, while the coal units are with weaker capability. The fluctuation of wind power is with the least fluctuation on a minute basis, and that of PV is on second basis. So in the aspect of system capacity configuration, the adjusting function should be fully considered.

(3) Accepted capacity of access point system: the accepted capacity of the access point system of the grid mainly refers to the density of access point system. It is basically indicated by short-circuit capacity. The bigger the short-circuit capacity is, the higher system density of the access point would be, and more suitable for renewable energy to switch in.

Table 2-6 Gradeability comparison of coal, natural gas and hydropower generating units

Unit Type	Gradeability of the Generating Units (%·min⁻¹)
Coal-fired Unit	2
Natural Gas Generating Unit	20
Hydropower Generating Unit	30

The structural proportion of power generating in the integrated multi-energy system planning not only should guarantee the technical operability, but also satisfy the maximum economic benefits. It means a stable operation of the grid system should be ensured on technical level, and also the economy of investment cost and operational income of later stage should be considered.

Because of the randomness of wind and PV power, the output capacity can be calculated by measuring the fiducial capacity of the intermittent renewable energies. The fiducial capacity of renewable energy means: in the density function of renewable output probability, certain

output capacity where some confidence level exists. This model fully considers the random changing factor on the system capacity such as wind speed and illumination, while also calculating the impact caused by random fluctuation of natural resources. The calculation on fiducial capacity can be achieved by Monte-Carlo simulation.

2.2.3 System optimal control technology of Integrated Multi-energy System

System optimal control technology of the integrated multi-energy system is the key technology to ensure the stable operation of the system. In this paragraph, some typical system optimal control technology of the integrated multi-energy system will be introduced.

(1) Optimized control on integrated multi-energy system

The objectives of combined operation of the integrated multi-energy system composed by wind power, solar power and hydropower generating units are: eliminating or reducing the intermittency and fluctuation of output efficiency by wind and PV generation so as to reduce the operational risk on the grid caused by this kind of instability. In the operation process, such integrated multi-energy system should fully consider economic and environmental profit. Therefore, while creating a dispatching strategy of integrated multi-energy with wind, solar and hydropower, the mentioned objective should be taken into account.

The three coordinating control models of integrated multi-energy containing wind, solar and hydropower are as follows:

- Normal operation: The integrated multi-energy systems will transmit as much electric power as possible to the grid. At this time, the renewable energy is on the highest working efficiency point, and the electric power generated by it can be directly transmit to the grid.
- Limited operation: the integrated multi-energy system combining wind, solar and hydropower will operate per the expecting input capacity based on grid configuration so that the goals like peak-shaving or proactive load control can be reached. Hydropower is used for complement the fluctuation of wind power and PV, and the imbalance between the electric powers dispatched into the grid. As at this moment the system operator can continuously change the electricity quantity coming into the grid, so the fluctuation of wind and PV power is inevitable, while hydropower will go through start-stop, halt and adjustment on output capacity, therefore inappropriate control will impact the safety or life-span of the hydropower units.

- **Balanced operation:** this model is applied for alleviating the output capacity fluctuation of wind and PV energy, which is to release the voltage and harmonic wave imbalance with the grid on public coupling point so that high-quality electric power can be transmitted to the grid. The managing system need extra control module to fix the electric equilibrium value, and set out control orders to the generating unit of the integrated multi-energy system.

Generally, the predictability and controllability of wind and PV energy is not as good as hydropower. In order to reduce its impact to the grid, firstly the locating region and the respective volume where the integrated multi-energy system should be considered, and also the following indicators should also be inspected:

- **Level of control difficulty:** the workload of operating capacity for reaching the control objective;
- **Control loss:** the impact on all devices when control measures are taken;
- **Total output power capacity:** how much total capacity can be generated after control;
- **Influence on power quality:** the influence on power quality after control. By examining these factors, the control objective is determined. By correlation, control speed and density are determined to finally reach the goal of coordinating control.

Meanwhile, following safe constraints should be considered in the joint operation of integrated multi-energy:

- **Constraint on capacity balance:** it refers to the constraint used for balance the power generation and electricity consumption at any moment when the grid is operating. It's the primary condition for the power grid system to run safely.
- **Constraint on machine set output:** it mainly includes the constraint on maximum output capacity of wind and PV power, as well as on hydropower for its maximum and minimum level, reservoir storage, hydro-electro transforming efficiency and daily flow.
- **Ramping rate constraint of the machine set:** it mainly refers to how much extra capacity that a machine set can generate on a increasing or decreasing situation in unit time. This characteristic is determined by the physical property of the machine set. To carry out capacity stabilization, the ramping rate constraint of the machine set must be considered.
- **Spinning reserve constraint:** it refers to the adjusting capability on the positive and negative capacity left out in the grid system. In order to guarantee a safe and stable operation of the

grid, when the optimizing dispatching strategy is making, it must leave out enough back-up capacity to pretend all kinds of irregular situations.

(2) Virtual power plant technology

A virtual power plant is realizing the aggregating and coordinating optimization of multiple types of energy like wind, solar, hydro energy, heat and storage etc., and serving as a special plant to participate with dispatching system of electricity market and grid operation. This concept emphasizes a control effect showing externally as a whole. The renewable energy, representing by wind and solar energy, is obviously intermittent and strongly fluctuating. If massively switching in several units of renewable resource of singular form into the big power grid, there will be very serious systematic stability issue, and will severely restrict the development and utility of the power from renewable energy in a large scale. Virtual power plant provides a model where the power from renewable and traditional energy can be optimized and integrated. It can show a stable power transmitting characteristic for the micro-grid by the support of coordinating adjustment and policy decision. The main technologies include: multi-energy flow coordinating control, smart meterage and information communication etc.

In the integrated multi-energy system of renewable and thermal power, the thermal machine set is a stable power source and has a supportive effect on the generating dispatch for clean energies such as wind, solar and hydropower. It also stabilizes the impact to the grid caused by the random fluctuation of new energies, and guarantees a safe supply of the electric power and a stable systematic operation.

As shown in Fig. 2-5 and 2-6, the integrated operation of renewable energy and thermal energy based on virtual power plant is to form a virtual power plant composed of wind power plant, PV power station, hydropower plant and thermal power station, and use the polymerizing effect and coordinating dispatching-optimizing algorithm of the virtual power plant to serve as a measure to stabilize the power fluctuation of renewable energies. Such method forms a new strategy to make bundling dispatch of new energy and regular power source by taking advantage of the integrating feature among power sources, so that the capacity putting into the grid can trace the load change, while introducing the stimulating information on price from the electric market. In such way, it creates condition for the final combination of thermal power units into the grid in best economy. Virtual power plant fully takes advantage of the coupling effect of multiple power sources and achieves dispatch control and coordinating optimization on economic and environmental profit.

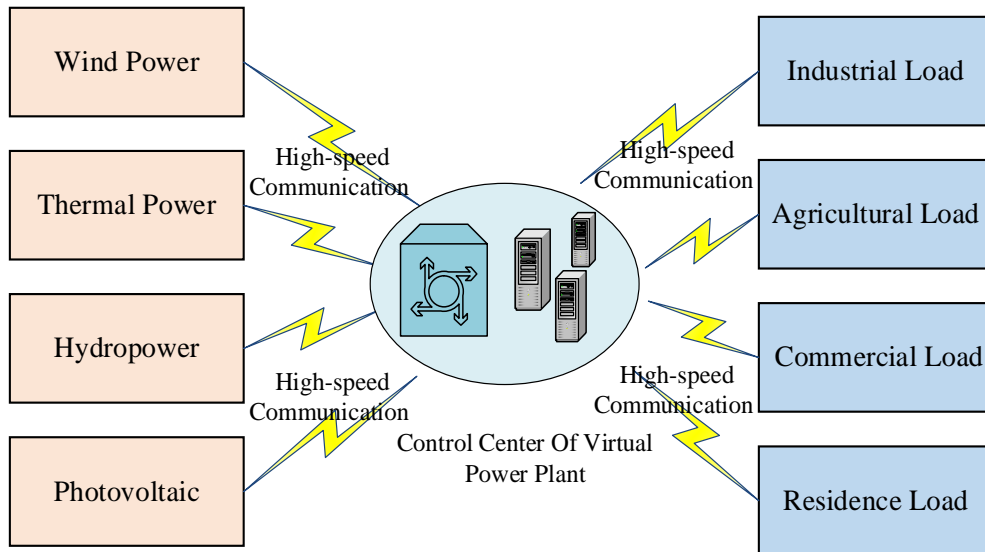


Fig. 2-5 Virtual power plant technology

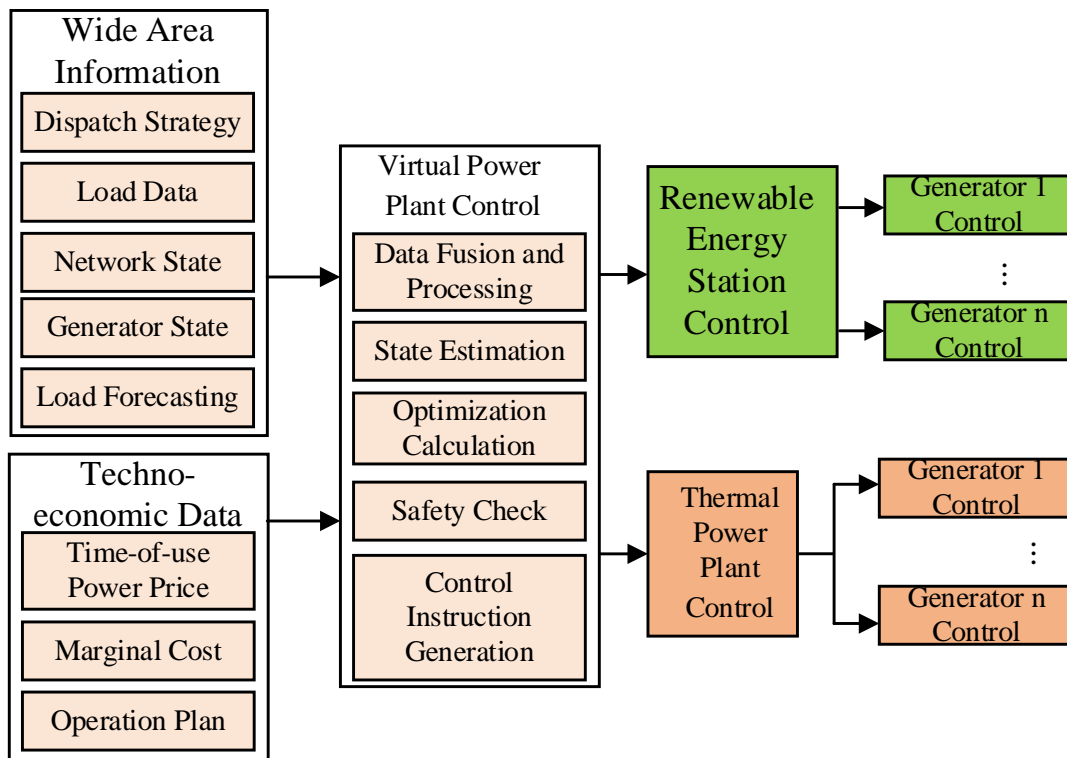


Fig. 2-6 Complementary control of renewable energy and thermal power based on virtual power plant technology

(3) Stabilizing technology by energy storage for renewable energy capacity

Energy storage is widely applied in the power grid. In the power generating system of renewable energies representing by PV and wind power, in order to ensure a high digesting proportion, an energy storage device of certain volume should be installed. It plays an important role in all links such as generation, transmission, dispatch and consumption etc.

The energy storage in the power generation system of renewable energy, mainly include following integrating functions:

- (1) Stabilize the capacity output of renewable energies.
- (2) “Peak-shaving”, assists renewable resources to carry out load stabilization.
- (3) Achieve an orderly power generation, and flexibly take advantage of time-of use (TOU) and to realize the economic operation of renewable energies.
- (4) Offering voltage and frequency support under “off-grid” circumstance.

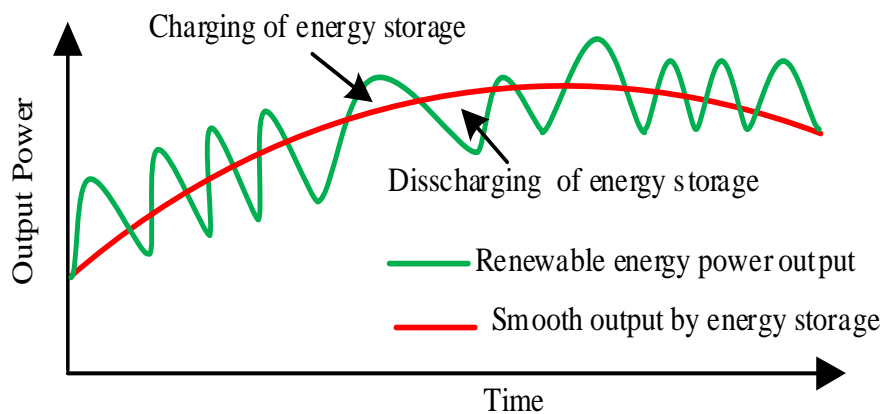


Fig.2-7 Energy storage smoothes fluctuations of renewable energy

Based on the characteristics like charging-discharging operation, satisfying both volume and capacity needs as well as excellent environmental protection etc., energy storage system can fully bring the advantages of the renewable energies into play, balance its random fluctuation, maintain system stabilization and improve electricity quality. Installing a synchronized generator or energy storage unit can stabilize load fluctuation and achieve peak-shaving. It also integrates with generating technology of renewable energies such as wind and PV power so that the capacity fluctuation initiated from renewable energies by natural condition change is reduced. It also stabilizes the capacity output, enhances the schedulable function of generating system of renewable energy, and achieves peak-shaving and scheduled power generation.

Constructing an integrated multi-energy system which combines renewable energy and energy storage shall effectively improve the function of intermittent power. Aiming at the fluctuation of output capacity of renewable energies, it takes advantage of general output of the energy-storing integrated multi-energy system to make short-time fast compensation by fast-responding capacitors through the configuration on energy storage technologies of multiple capacity type and energy type. It supports the capacity with energy storage, and provides long-

term support with energy storage of energy type such as combustion turbine etc. With such actions, the capacity fluctuation of renewable energy is totally stabilized and complemented. By external looking, renewable energy is a stable and reliable power resource that can be switched in with high penetration rate so that the adjusting capability of power system is improved, and the adaptability of the power grid is enhanced. It also facilitates the renewable energies to be switched into the power in a large scale.

(4) Virtual synchronized generator technology

As currently the majority of wind and PV power source are switched into the grid by power electronic converter, yet the power electronic converter has essential difference comparing with traditional synchronized generators. Because of the characteristics such as fast dynamic response, rather small overload rating, low rotational inertia and low short-circuit capacity etc, the power electronic converter initiates impact on the static and dynamic stability to the grid in a way that can't be ignored. The synchronized generator in the traditional grid has excellent inertia and damping characteristic, and can participate in the adjustment for grid voltage and frequency therefore it has a natural and friendly advantage for the grid and a quite mature control technologies. If the renewable energies that switch in by inverting style is able to has the same feature like synchronized generator, then the control and digestion of renewable energy can be simpler.

Virtual and synchronized generator technology is mainly to introduce energy storage of certain proportion on the DC side of the inverter. And by characteristics such as stimulating the body of synchronized generator, active frequency change and reactive voltage adjustment, it makes an inverter very similar to a traditional synchronized generator on operation organism and outer feature so that the renewable energies can connect into the grid "friendly".

At present, virtual and synchronized generator technology has been applied in several demonstration projects in China, for example, Wind-solar-energy Storage-Transmission in Zhangbei and Zhongxin Distributed Virtual Synchronized Generator in Tianjin Ecological City. This technology can solve the compatibility issue when new energies switch into the grid, and it's one of the most effective ways to realize the grid connection of large-scale distributed power source.

(5) Energy management technology of multi-energy flow

Energy Management System (EMS) is the core system to guarantee the system safety and high-efficient operation of the power system. The integrated multi-energy involves energy management technology of multi-energy flow coupling system. For an interconnection of

multi-energy, new circumstances such as big time span and scale, the existence of energy form with various heterogeneities. So in order to face the application of the integrated multi-energy system, new energy management technology of multi-energy flow is needed.

Energy management technology of multi-energy flow mainly involves the following three aspects:

- The estimation on multi-energy flow status. The status estimation mainly targets as the “truth verification” for the operation data in energy system. Multi-energy flow system SCADA widely contains electric quantity and operation capturing volume of cooling and heating subnet, so the type of data is relatively complicated, and has a certain scale of redundancy and interconnection relation. It requires re-issuing the status estimation that is suitable for multi-energy flow, so that operational data is check and reviewed through the redundant data.
- Safety evaluation and control of multi-energy flow. In the electricity system, the safety evaluation and control is quite mature. There are technical regulations for static and dynamic stability and emergency control etc. But the safety evaluation and control for traditional cooling and heating subnet in the integrated multi-energy is rather weak. At the same time, interconnection of multi-energy flow will bring problems like risk-increasing, trans-boundary chain malfunction and safety border. These problems need to be solved by safety evaluation and control of multi-energy flow.
- Optimized dispatch on multi-energy flow. Different energy flow systems in the integrated multi-energy have distinct grid constraint and dynamic process. Optimized dispatch is to ensure the systematic stable margin, to achieve goals like maximum economic profits, lowest operation deterioration and biggest adopting ability and to distribute relevant dispatch order for a reasonable production transmission and supply of energy under the condition of the guarantee of a safe operation for the integrated multi-energy system.

2.3 Relevant frontal supporting technologies

The integrated multi-energy system focuses on the integration at power source side. Seeing from the “source-grid-load”, it also requires strong energy grid and highly effective information and communication technology to support the operation of the integrated multi-energy system. From the angle of supporting the operation of the integrated multi-energy system and improving operational efficiency, this paragraph chooses technologies which are

quite mature and with certain technical advantage: UHV transmission technology, information and communication technology and energy big data technology.

2.3.1 UHV transmission technology

For the big energy base which is far from load center but with abundant resources like wind, solar, coal, natural gas and hydropower, the generated electric power requires a electricity transmitting channel to the load center. This makes UHV transmission technology which covers long distance, big capacity and low loss on electricity transmission a consequent choice. The transmission capacity of UHVAC transmission cable of 1000 kilovolt can reach more than 5 GW, is 5 times of that in 500 kV. Greatly improve UHV transmission technology, and cooperate with bundling transmission of coal, water, wind and solar power.

UHV transmission technology can be divided into UHVAC transmission technology and UHVDC Transmission Technology.

(1) UHVAC transmission technology

UHVAC transmission technology refers to the transmission technology with over 1000kV and above voltage class. Increasing the power transmission voltage can effectively enhance the natural capacity and static stability, while obviously reducing circuit wave impedance by increasing fission number and fission radius. In this way, the power transmission capability is improved. Along with the elevation of voltage class, the flow in line current is reduced so it can effectively reduce the resistance and corona loss in the transmission, and enhance the transmitting economy.

(2) UHVDC Transmission Technology

UHVDC transmission technology refers to the transmission technology with over ± 800 kV and above voltage class. The main features of UHV transmission technology are big transmission volume, long electricity-transmitting distance and high voltage. It can be used for asynchronous interconnection on power system. Its controlling pattern is flexible and swift. It can achieve valid adjustment for flows, and can effectively inhibit the power oscillation from the paratactic AC circuit.

2.3.2 Information and communication technology

In a circumstance where multi-energy is widely integrated, the needs for the open interconnection, safety and controllability and highly-effective intelligence on various energy

sources like cooling, heating, gas and electricity will be higher and higher. It requires information and communication technology as a support. The information and communication technology for the integrated multi-energy system should own capabilities like multiple information collection, flexible grid access, highly-effective grid transmission and storage.

The communication network of the integrated multi-energy system is to realize a business network with information collection and sharing, multiple adjusting strategies, customization on user consumption need and diversified services for multi-energy. Its general structure should be multi-level distributing style. It combines several factors like distributing feature of communication node, transmission requirement on the business information it supports and construction cost etc., and chooses many kinds of communication technology to form a compound network that suits into the local conditions. The communication network of the integrated multi-energy system can be divided as remote communication network and local communication network.

(1) Remote communication network

Remote communication network is a long-distance data communication network from all types of collecting source measurement unit and smart terminal device to all kinds of supporting system (for example, dispatch control, information collecting, monitor center and energy-using bidirectional interactive supporting platform etc.). Remote communication network should be equipped with high bandwidth and transmitting speed to make sure the transmission of big data communication is bidirectional, on-time, safe and reliable. Remote communication network is generally built on optical fiber, and uses 4G/5G wireless and power line carrier as supplement.

(2) Local communication network

Local communication network refers to a short-distance communication network for message interaction between smart collecting terminals, concentrators, interactive terminal and smart energy-using devices. Local communication network should possess certain bandwidth and transmitting speed to ensure a bidirectional, short time delay, stable and reliable transmission. For the communication network from the energy stations to the users that switch into the network locally, it mainly adopts methods like bandwidth/narrow band power line carrier and optical fiber composite low-voltage cable, and in some location the micro capacity wireless technology can be used; for family or user internal communication network, it mainly uses wireless technology like ZigBee/WiFi to realize local networking.

2.3.3 Energy big data technology

Big data is a new technology in the IT field, and a current study hotspot. Applying big data technology into the energy field is an innovative trend to push industrial development. By combining data like energy producing operation data, consumption data, device status data, customer information, external economic information and meteorological system, the technology can fully dig data on energy data utilization to form a further discovery of deeper layer and rules on all links like energy production, transmission and application so as to provide a more effective support on electricity decision. In this way, the efficiency will be improved.

The development of information and communication technology, and its promotion and application in the energy system, produces a huge amount of data. These data not only contains operation information like voltage, current, thermal power and load etc., but also covers all kinds of relevant information like geographical information and climate. Storing these data, along with an effective management, can improve the capability on comprehensive and real time perception, and it has an important effect for the grid to operate safely, reliably and economically. In the integrated multi-energy system, the application of big data can efficiently combine data of multiple sources, and achieves function like: system output efficiency prediction, digging characteristics for energy-using behaviors and setting energy efficiency analysis etc. as shown in Fig. 2-8.

Energy big data is currently a hot study topic in China. Big data technology integrates cloud computing technology, AI smart technology and technology on ubiquitous internet of things and put them into wide use in energy fields. It is one of the important technical directions for the development of “intelligent” energy system and energy internet. A bunch of technical achievements have been formed in fields like smart electricity dispatch and consumption, power supply service and renewable efficiency prediction. For example, the malfunction diagnoses and power supply service system based on big data digging on wind power generator set. The application of such cutting-edge technologies can effectively enhance the energy efficiency, control level, reliability and power supply quality for the integrated multi-energy system.

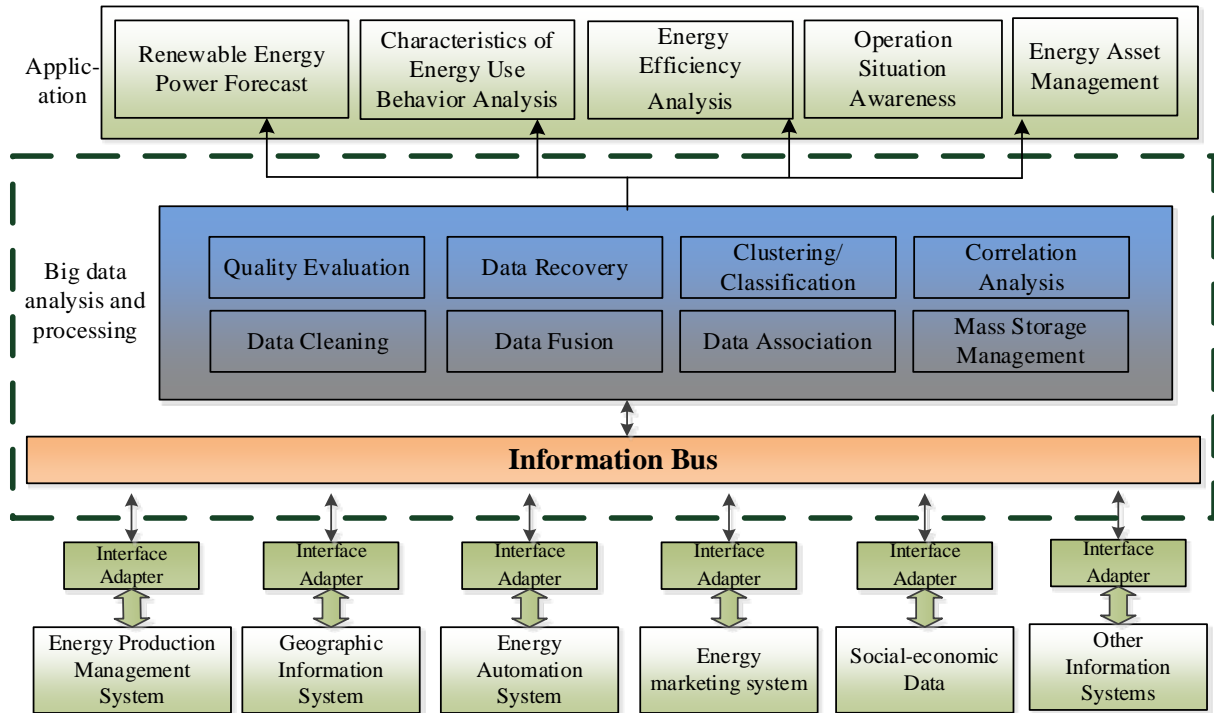


Fig. 2-8 Energy Big Data Technology

2.4 Potential business model of the integrated multi-energy projects

A good business model is the key to solve the investment, financing and operation issues for the integrated multi-energy. The investment, financing and operation of the integrated multi-energy projects involves business model. Differing from the investment and operation of traditional energies, the integrated multi-energy involves many stakeholders therefore it's quite complicated. As a result, suitable business model is needed. The research summarizes all possible business models for integrated multi-energy projects.

2.4.1 BT model

BT model, known as “build-transfer”, is a new investment and financing construction model. In this model, the government authorizes a company with concession agreement to financing the construction of an integrated multi-energy project. When the project construction passes the acceptance check, the government will redeem it and uses the capital from financial budget to pay the company for its total investment and reasonable return. In the BT model, the project initiator signs contract with investors so that they will be responsible for the project financing and construction. Then the investors shall transfer the finished project in a scheduled time back to the initiator. At this point, the initiator will pay the investors with project total investment and confirmed reward by stages based on the signed repurchase agreement.

2.4.2 BOT model

BOT model, is short for “build-operate-transfer”. It’s based on the agreement reached by government and energy corporate. Government would issue a concession to the energy corporate which allows the corporate to raise the capital in a certain period of time for the construction of an infrastructure. The corporate will manage and operate the facility and its relevant products and services. In the BOT model, the project initiator will sign a concession agreement with the service provider with which the provider can take on the project investment, constructing operation and maintenance. Within the prescribed time frame, the service provider will reclaim the capital and gain reasonable profit by developing operation and other preferential from the government. When the concession period is over, the provider shall return the fixed assets to the government for free.

2.4.3 PPP model

PPP model. Public Private Partnership (PPP) is a model where governmental department and social investors establishes a cooperative partnership to offer the construction and relevant service for the integrated multi-energy projects. PPP model is a business model where the governmental departments absorbs social capital and jointly put the funds or resources into the integrated multi-energy project, then the social investors will build and operate the project and gain mutual profit per the proportion of the contract. But there is a time limit on the operation time. This kind of business model fits for construction of big infrastructure and social public facilities and relevant services.

2.4.4 DBFO model

DBFO model means design-build-finance-operate (DBFO). It’s a typical model of PPP. In this model, the government sets the public service standard and the energy company designs and builds relevant facility based on it to offer service, while also in charge of the financing and operation. In the meantime, as the main service buyer, the government will pay user charge to the energy company. When the operation period is over, the related facility will be transferred to the governmental departments. We can see that in the DBFO model, private sectors play a very important role in all phases like design, building, financing, operation and maintenance. DBFO model is fit for suppliers to carry out electricity-replacing design, construction, financing and operation/maintenance for infrastructure and social public facilities where they would get operation and maintenance income in a certain time period. The advantage of DBFO

business model is the supplier and the government shall take the project risk together. The innovative point of this business model is the usage on private equities and the bundling of 2 phases which are design/construction and electricity replacing operation/maintenance. It encourages the supplier to design and build the infrastructure of the integrated multi-energy project in a more energy-saving and highly efficient way. Besides constructing the facilities per budget, the supplier should also operate and maintain these assets in a high-efficient pattern in a certain period of time, and to gain profit based on contract proportion. Generally, the time frame is 30-35 years.

2.4.5 EMC model

EMC model. Energy performance contracting (EMC) is a marketized and energy-saving service mechanism in which the professional energy-saving service company provides services on energy-saving service, energy-saving diagnose, financing and rebuilding to customer companies through energy service contract, and get investment return and feasible profit by sharing energy-saving benefit. The essence of this model is an energy-saving way to pay for the total project cost with the expenses saved from the energy. Such energy-saving investment method allows customers to upgrade the factory and the facility with the future energy-saving profits so the operation cost is reduced; or the energy-saving company offers energy-saving services by promising the benefit for the project or contracting the total energy cost. Energy performance contracting contains 5 models: sharing energy-saving profit; depositing energy expense; guarantee energy-saving volume; financing renting; compound model.

2.4.6 Integrated distributing-selling model

Integrated distributing-selling model. Integrated distributing-selling model means an operation model in which the power company carries out both power distribution and selling service. Operating in this model, the power company not only benefits from power selling service, but also gets power distribution profit from power distribution grid. The companies that are distributing-selling integrated would easily take the initiative in the power selling market and become secure power selling company due to their ownership on power distribution. At the same time, they can actively provide value-added service with grid distributing resources such as contract energy management and response at demand side. These companies are also able to participate in the electricity assist market with their customer resources.

2.4.7 Trading cooperative model

Trading cooperative model. Trading cooperative model is a cooperative model in which several power companies participated together to combine the power generation and selling. The members of the cooperation have power generation resources, and sell electricity to other members in a trading cooperative way. Meanwhile, part of the selling income gaining by power selling companies will be put into the construction of power plant so that a win-win scenario is achieved for both generating and selling parties. The biggest advantage for the power selling company in the trading cooperative model is that they can acquire excellent power generating resources, especially for those distributed renewable power generation stations. In this model, power is sold to power-selling companies of pure green electricity, and part of the income from the selling companies shall be invested or distributed back to the stations. So the power stations are more willing to join this trading cooperative model, whereas the power purchasing cost of power selling companies will be comparatively reduced.

2.4.8 Wholesale and retail model

Wholesale and retail model. Wholesale and retail model refers to the new measures as “develop market at power selling side and allow 5 kinds of different market entities to become power selling companies” are raised in the electricity system revolution so the electricity market has formed a “multiple buyers with various suppliers ” competitive pattern. This makes the electricity selling a new business model. Power sellers can offer users with stable and favorable electricity price, customized service pack or attach relevant value-added information to attract customer resource and purchase electric power in the market on behalf of the users. The transmitting and distributing grid is equally open to power generating agencies and users. Power generating agencies and user will negotiate for a competitive deal. The competition in power selling market can cut power using cost. The users has the choosing right is good for improving service quality of selling power and electricity consuming level of users.

2.4.9 E-commerce model

E-commerce model. E-commerce model means between companies and between company and users, direct deals are made through the internet. The internet can closely connect together scattering users in the energy system, differentiated energies and diversified commercial entities, and expand the interactive range and frequency of market members, cut down trade cost and greatly improve the convenience and presence of the market members when they participate in the energy deal. Meanwhile, it also can fully measure, collect and analyze

abundant data information of the whole process from production to consumption. In this way, all involving links becomes more visible, measurable and controllable. It enables the users to have a deeper understanding on their own energy consuming behaviors, and system operating agencies can have a more accurate judgement on the device operational status.

Chapter III: Case Study of Integrated Multi-energy System

3.1 “Wind-Solar-Energy Storage-Transmission” Integrated Multi-energy Project in Zhangjiakou, Hebei Province, China

3.1.1 Project overview

“Wind-Solar-Energy Storage-Transmission” Integrated Multi-energy Project in Zhangjiakou, Hebei Province, China (hereinafter referred to as “the demonstration project”) locates in Zhangbei County of Zhangjiakou City of Hebei province. It’s a new integrated energy demonstration project with the largest scale and highest comprehensive utilizing level. This project integrates “wind power generation, PV power generation, energy storage system and smart electricity transmission”, and it’s the first to demonstrate the advancement and innovation of the joint power generation of wind-solar-energy storage²³.

The demonstration project plans to build 500MW wind power, 100MW PV power and 70MW energy storage: among which, the phase I of the project will build 100MW wind power, 40MW PV power and 20MW energy storage and has finished and been put into use on December of 25th of 2011; in phase II, the project plans to build 400MW wind power, 60MW PV power and 50MW energy storage. By the end of 2014, except for the energy storage and big-volume wind power generator, all other volume has been putting into the power generation. The demonstration project adopts the world’s first technical route of “power generation of wind-solar-energy storage”, and starts technical studies on integrated mechanism of power generation of wind-solar-energy storage and optimized configuration, on system integration for multi-type battery energy storage stations, integrating technology on joint power-generating and full view monitor and coordinated control. It successfully achieves a smooth output on power generating by new energies, and has answered the worldwide problem on massive development and utility. The demonstration project has made the clean energies as the most possible power source form that may replace the thermal power generation.

3.1.2 Key technologies

- **Application mode for massive wind-solar-energy storage**

²³ Project information is provided by China State Grid Xinyuan Zhangjiakou Demonstration Power Station Co., Ltd.

The project firstly created application mode for massive wind-solar-energy storage-transmission and fully reveals the pattern of integrated wind-solar-energy storage and interconnecting mechanism that delivered out of the grid. It also establishes a theoretical model for massive wind-solar-energy and supports the demonstration project construction and exemplary operation of national wind-solar-energy storage-transmission.

(1) Build up an energy storage and wind-PV-output integrating model of accounting multiple application targets, multiple time scale and multi-need response;

(2) The first to establish a relating theory model on power generation system of wind-solar-energy storage and grid interconnection;

(3) The first to develop partitioning software on volume configuration of joint power generation of wind-solar-energy storage and has been proved by the demonstration project.

- **Key technology on wind-solar-energy storage grid-tied active control**

It conquers the key technology on wind-solar-energy storage grid-tied active control and raises a control active-reactive coordinating control method. It builds a dispatching model for collecting area for wind-PV power generating and a hundred-trillion-level full view monitoring system for wind-solar-energy storage which is developed by the own team. The technology also achieves a friendly interaction between new energy generation and grid dispatch and improves the admission capability on new energies for the grid.

(1) Make break through on information interaction of multi-type device for joint power generation of wind-solar-energy storage. Establish a unified information model and communication protocol; create an all-in-one instant message blending platform of high speed;

(2) The first to achieve virtual full view monitor and comprehensive control for the quaternity of wind farm, PV power station, energy storage station and smart transformer substation.

(3) First to set the output optimization during sequential multi-configuration and automatic coordinating control for multi-source active voltage; achieves functions like capacity stabilization, plan tracking, peak-shaving and frequency change, as well as voltage control and has reached a power generating quality very similar to regular power source.

- **Massive battery group and massive integration on battery storage**

It conquers the key technology on massive battery group and massive integration on battery storage. The project group has developed a stratified instant interconnecting control system. The project built the world's largest multi-energy storage power station, and its critical

function parameters such as control accuracy, energy transforming rate and responding speed has reached world's top level.

(1) Raise massive grouping technology and battery system cascading technology accounting for the battery dynamic consistency. It realizes the biggest system integration on energy storage station of multi-type battery type in the world, and its energy transformation rate is >90%.

(2) Develop an energy storage monitor system that interconnects the centralized control and distributed adjustment, which makes the general responding time of energy storage station is <900 millisecond and an output deviation that <2%.

(3) Develop software for the coordinated control on energy storage station and energy management and it is the first to achieve multiple advanced application functions in the same energy storage station.

● **Status evaluation technology on massive joint power generation of wind-solar-energy storage**

It conquers the key technology on status evaluation technology on massive joint power generation of wind-solar-energy storage, and builds a status evaluation system based on double index which are reliability and power generation performance. The technology develops the first set of evaluation and decision-assisting system for generation device of wind-solar-energy storage, and guarantees a safe and reliable operation for demonstration stations, and plays the leading role for maintenance technology of national demonstration.

(1) The first to set the index and method for status evaluation on power generation of wind-solar-energy storage and establishes a highly efficient evaluation system.

(2) Develop the first set of decision assisting system that combines status evaluation and analysis, smart trouble diagnose and overhaul guidance as well as production auxiliary management of power stations.

(3) Publish a series of standards that cover adjustment and acceptance check, operational maintenance and technical monitor.

● **Integrating the most advanced equipment technologies of China**

It integrating the most advanced equipment technologies of China, and is the first to build a wind-solar-energy storage-transmission demonstration project with the largest scale, highest smart level and a flexible operation method. It successfully demonstrates a integrated effect on elevating power generation quality for new energies and admission ability of the grid and

becomes a platform of technical achievement demonstration, key equipment inspection and scientific research hatching for new energy power generation.

(1) It builds up a demonstration platform for the first set of application for the self-owned advanced technical device of China, intensively demonstrates and compares application functions for several kinds of new wind and PV energy devices, and promotes the industrial upgrade for national new energy devices.

(2) First to achieve the application of straight-type SVG in new energy stations, and also achieves PV power station application in active adjustment of the grid for all day. This greatly improves the dynamic active supporting ability;

(3) The first to introduce the smart transformer substations into demonstration operation, and fully satisfies the applying researching need of different group status and proportion of wind-PV energy storage.

3.1.3 Project characteristics

The demonstration project aims at a new energy generation that is “grid-friendly”. It integrated advanced technologies in fields like power grid, wind power, PV power and energy storage which makes it a comprehensive demonstration project of new energy that combines characteristics like “advancing, flexibility, demonstrating” together.

(1) Wind farm

It was built in 2 phases and it covers different volumes in China like 1.0MW, 2.0MW, 3.0MW and 5.0MW, different manufacturers such as Goldwind, XJ Group Corporation and XEMC, and totally 177 units of different types of wind turbines including doubly fed induction turbine, permanent magnet direct-drive (PMDD) turbines and vertical axis wind turbine. It built the first grid connecting friendly wind farm with most unit types of China and leads the developing trend of bigger on-shore and higher efficient operation for the wind turbine.

(2) PV power station

The total volume of phase I PV power stage is 40MW including demonstration area and experimenting area. The demonstration areas are totally 28MW and all adopts polysilicon PV modules with fixing holder; the experimenting modules includes multiple models like polysilicon, monocrystalline, amorphous film, back contact and HCPV and match them with fixed, oblique monoaxial, flat monoaxial and double axial tracking systems to achieve a multiple grouping and analyzing comparison for different modules and tracking systems. In

consideration of factors like operation result of phase I and comprehensive cost, phase II of PV power station all installed polysilicon PV modules with fixing holders.

(3) Energy storage station

Phase I of the energy storage station covers 4 types of electrochemical energy storing batteries, including lithium iron phosphate battery of 14MW/63MWh, vanadium redox flow battery of 2MW/8MWh, gelled lead acid battery of 2MW/12MWh, and titanate lithium battery 1MW/0.5MWh. Phase II of the energy storage station adopts cascade utilization of the batteries from electric vehicles of 3MW, and 2 sets of 5MW virtual synchronized units of energy station style which makes totally 10MW. The rest of the 37MW energy storage will be put into demonstrating application in due time based on technical and product developing progress.

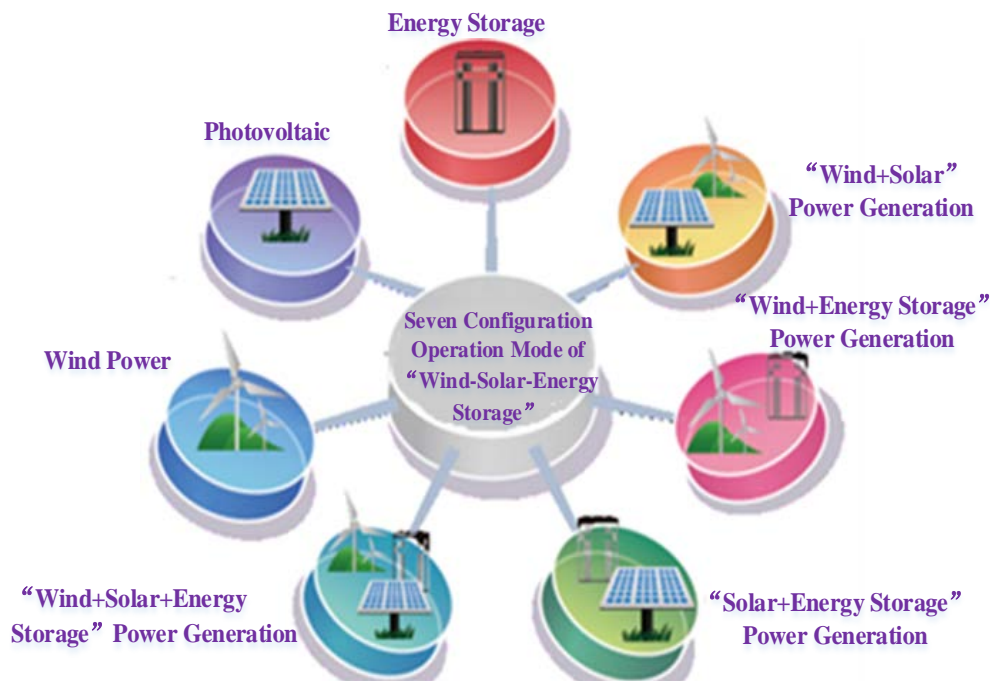


Fig. 3-1.1 Seven Configuration Operation Mode of “Wind-Solar-Energy Storage”

The demonstration project takes advantage of joint monitor system to coordinate and transmit of joint power output of devices like wind power generation, PV power generation and energy storage to achieve automatic configuration (as shown in Fig. 3-1.1) of 7 operation models of wind-solar-energy storage (wind, PV, energy storage, wind-PV integration, wind and energy storage integration, PV- and energy storage integration, wind-solar-energy storage integration). It also realizes functions like stabilizing power output, plan tracking, peak-shaving and change of frequency etc. by switching between the multiple configurations of wind-solar-energy storage integrated power generation operation model, so it achieves predictable, controllable and adjustable power generation from new energies in certain way.

The demonstration project masters key technologies on massive development and utilization of new energy by independent innovation.

- It solves the world problem on the adjustment of wind-solar-energy storage integrated power generation, and coordinately controls the superposition of output from wind power, PV and energy storage. It brings the instant charge-discharge characteristic of energy storage, and swiftly and accurately adjusts wind-PV output to make the total power output stabilized and controllable so it can reach regular power source level.
- It masters the all-item inspecting technical capability for devices of wind power, PV and energy storage, and facilitates a general level upgrade on the device while the device availability is also obviously improved. It solves the problem of massive wind power off-grid (massive off-grid incident has not been happened after 2013).

3.1.4 Social and economic benefit

Since the project was put into production, it generally runs stably, and has been outputting more than 4178 GWh of excellent green electric energy in total. By self-innovation and focusing on scientific research, the wind turbine units can improve their annual availability from 93.1% to 95.9%, and the PV annual electric-power output by 12.85%. Referring to international general model, and calculating per an annual electric-power output of 1.25 billion kWh, the demonstration project will save 42 tons of standard coal per year, and will reduce 0.9 million tons of carbon dioxide emission.

Based on actual practice, the demonstration project has made breakthrough on several key technologies. Of all these technologies, massive wind-solar-energy storage volume compounding ratio optimizing technology, integration technology and operational control technology have been adopted in projects in Qinghai Province, Gansu Province and Ningxia Province, and the promoting and application results has been quite good.

3.2 “Hydropower-PV” Integrated Multi-energy Project in Longyangxia, Qinghai Province, China

3.2.1 Project overview

The Gonghe county of Hainan prefecture, Qinghai province of China owns abundant solar and hydro energy. The whole area is with abundant illumination, and a strong solar radiation. The average daily duration of sunshine is 8 hours, and the duration of sunshine is 2922.6 hours if counting for several years, and the mean annual total solar radiation is 6564.26 MJ/m² so it's suitable to build up big PV power stations. The Longyangxia Hydroelectric Station is a massive comprehensive utilizing project with mean annual adjusting function. Its installed capacity is 1280 megawatts; mean annual electric-power output is 5942 GWh, and installed annual utilization is 4642 hours. The adjusting storage reservoir capacity is 19.35 billion cubic meters. It's with a big reservoir capacity and strong complementing capability. It operates and regulates in a manner as “use water to determine electricity, and use electricity to adjust water” so has the reservoir capacity and adjusting condition to integrate with PV power stations.



Fig. 3-2.1 Diagram of “Hydropower-PV” Integrated Multi-energy Project in Longyangxia

850 MW power “Hydropower-PV” integrated multi-energy project²⁴ in Longyangxia is the largest “Hydropower-PV integrated” project that runs in the world. It locates in the PV

²⁴ <http://www.hhsd.com.cn/develop/tyfd/>

generation park of Gonghe county of Hainan prefecture in Qinghai province, and its direct distance to the Longyangxia Hydroelectric Station is 30 km. It is the largest centralized integrated grid-connecting PV project of the world, and it's the first grid-connecting PV power station that adopts hydropower-PV integrated operation for generation control. Longyangxia “Hydropower-PV integrated” project takes advantages of the integration of hydroenergy and PV energy, and is based on the fast adjusting power of water turbines and reservoir of the water station to adjust the active output of the PV power stations in order to carry out a hydropower-PV integrated generation. Like this, the project achieves a smooth and stable generation curve, and effectively compensates the deficiency of independent PV power station. It also improves the system safety and stability to make the PV generation an excellent electric power that can compare to hydropower.



Fig. 3-2.2 Longyangxia Hydropower Station in the Yellow River

“Hydropower-PV” integrated multi-energy project in Longyangxia of 850 MW power connects to the back-up inline space of already-built Longyangxia Hydroelectric Station with a wire of 330kV per time, and connects to the grid along with the Longyangxia Hydroelectric Station with the sending wire of 5 times of the Longyangxia Hydroelectric Station. The PV power station is developed and constructed in 2 phases. Phase I is 320 MW with the design of an annual electric-power output of 498 GWh, and it has been put into generation in December

of 2013; Phase II is 520 MW with the design of an annual electric-power output of 936 GWh, and it has been put into generation in September of 2015.



Fig. 3-2.3 PV Power Station in Gonghe County, Hainan State, Qinghai Province, China

3.2.2 Project characteristics

Solar-PV generation has characteristics such as randomness, intermittency and periodicity, and these make a drastic daily change for PV power output. Hydropower-PV integrated multi-energy project makes use of adjustable reservoir capacity of the hydropower station and the fast adjusting capability of the water turbine generators to raise the concept of a joint operation of hydropower-PV generation, and optimizes the electricity quality of PV power stations, improves the peak-shaving and back-up capability of the hydropower station. In this way, a win-win situation is reached by hydropower-PV integrating generation, and offers a safer and more stable electric power for the grid.

(1) This project sees the 850MWp PV power station as “virtual water turbines” to connect into the Longyangxia Hydroelectric Station. And by the swift adjustment of water turbines, the crenellated PV power source which is intermittent, fluctuated and random with a unstable capacity, is adjusted into a smooth and stable power source which is more balanced, better, safer and more friendly. Then the system will use the electricity quantity of both power sources, and put it into the grid through the sending channel of Longyangxia Hydroelectric Station. Massive experiment data shows that the peak-shaving and frequency change function of Longyangxia Hydroelectric Station hasn’t been affected, but improved instead.

- Save spinning back-up capacity of the power system: 70%, and the capacity is about 400 to 600 thousand kW.
- Improve the peak-shaving and frequency change function of Longyangxia: 18% (sunny days), 9% (cloudy days), 5% (rainy days).
- Improve the transmission capability of Longyangxia: 22.4%.
- Improve the electricity quality of the grid: balanced, excellent, safe and more friendly.

(2) The PV park is also a demonstration base of national solar-energy generation of hundred trillion scale. In the demonstration base, there are 5 experimenting zones has battery module, inverters, holder pattern, design comparison and comprehensive comparison etc.; 2 outdoor testing platform of modules and inverters, and has reserved experimenting zone for future new technology and products.

(3) The demonstration base includes module and inverters from domestic and international famous manufacturers. It covers the most advanced domestic and foreign technologies and chooses 23 kinds of modules, 21 inverters; shows 30 types of design theories and 13 tracking technologies. At the same time, the demonstration base develops a set of online monitoring and data comparing-analyzing system. The system installs online monitoring sensor devices and uses them for real time collecting and automatic analysis for generation data of the power stations. It provides a demonstration platform for design, equipment R&D, standard setting, operation management and investment profit analysis etc. for the PV industry.

3.2.3 Project achievement

The project received the first award of the scientific and technical progress of State Power Investment Corporation. *The Joint Operation System and Method of PV and Hydropower Stations* won national patent. The scientific achievements of this project are:

(1) Raise the concept of “virtual hydropower”; set the control principle and strategy for hydropower-PV integrated; compose experimenting solution and program of massive hydropower-PV integrated; point out the device function and characteristic for the hydropower station to participate in the adjustment.

(2) It’s the first example in the world for hydropower-PV integrated technology. The achievement is an international advanced technology and has provided a new integrated multi-energy developing model for the clean energies in China.

(3) Research and practice of Longyangxia hydropower-PV integrated project show that the requirement on the adjusting reservoir capacity of the hydropower station is not high, so all hydropower station with certain reservoir capacity can install it.

(4) It can integrate and adjust mutually with PV power station. Hydropower-PV integrated technology has a widely promoting value.

3.2.4 Social and economic benefit

“Hydropower-PV” integrated multi-energy project not only can elaborate the fast adjusting capability of hydropower generation, supplement the active output of the PV power station, improve PV power quality; but also can improve the general economic profit of the project by prior arranging PV power generation assisting by hydropower generation. Since being put into use, the PV generates power as the basic load of the power source group and avoids the power limitation and solar power curtailment problem from the independent PV power station. By using the fast adjusting capability of water turbine generators, and the adjusting capability of the Longyangxia Hydroelectric Station to adjust the active output of PV power station, the objectives like stabilizing PV generation curve and improving electricity quality of PV power generation can be achieved.

By hydropower-solar integrating, the annual utilizing hour of the sending wire from Longyangxia Hydroelectric Station can be improved from 4621 hours to 5019 hours. The economic profit of the hydropower station is greatly elevated, and the value of state-owned asserts has been secured and improved. 850 thousand kW power “Hydropower-PV” integrated multi-energy station can generate 1494 GWh electricity per year. Calculating into thermal power generation, it means to save about 183.56 thousand tons of standard coal for each year, and reduces about 480.9 thousand tons of carbon dioxide emission, sulfur dioxide emission of 1560.56 tons, and oxygen compound emission of 1358.34 tons, and a better social ecological environmental benefit is created.

3.3 APEC ESCI Best Practices Awards: Penghu Dongjiyu Microgrid

Small Power Supply System of Chinese Taipei

3.3.1 Project overview

Penghu Dongjiyu Microgrid Small Power Supply System of Chinese Taipei won APEC ESCI Best Practices Awards: 2017 Silver Award of Smart Grid²⁵.

The Dongjiyu, Xijiyu, Dongyuping, Xiyuping and surrounding islets were designated as the South Penghu Marine National Park in October 2014. The area encompasses rich ocean resources, with 39 families and 203 species of fish, 12 families, 35 genus, 133 species of stone coral, 2 families, 7 genus, 19 species of Octocorallia, 1 family, 1 genus, 2 species of Hydrocorallina recorded. In terms of large benthic macro invertebrates, there are 29 families and 62 species of Mollusca, 12 families and 24 species of Echinoderms, and 8 families and 22 species of Crustaceans that are recorded. Investigation of algae resources have recorded 71 different species of algae. As such, the South Penghu Marine National Park is a very important oceanic resource to our nation. In the early days, the Dongjiyu has acted as the transportation hub for trading between Chinese Taipei and mainland China. It even received the name "Little Shanghai", resultant to the traces of bustling activity in historical houses on the islet. Dongjiyu's geographical location is at longitude 119°40'21", latitude 23°15'50". The annual sunshine duration of Dongjiyu is 2,181.7 hours, which indicates it is extremely suitable for photovoltaic power development.



²⁵ <https://www.esci-ksp.org/archives/project/penghu-dongjiyu-microgrid-small-power-supply-system>

Fig. 3-3.1 Penghu Dongjiyu microgrid small-scale power supply system: remote monitoring system.

The combination of diesel generators and smart micro-grid will not only improve the power quality and stability, but also enhance the penetration ratio of renewable energy resources by introducing the automatic controlling function. Significant reduction of fuel consumption will also be a major plus generated from this innovative technology.

The existing power generation system on Dongjiyu is composed of 4 diesel generators, namely 3 sets of 200 kW and 1 set of 300 kW, with the total installed capacity of 900 kW, and 86.4 kWp PV system. The annual power generation of PV system is evaluated according to the investment parameters. The PV module area is 1.63m²; the maximum power of PV system is 86.4kWp with 85.71% of performance ratio (PR); the PV module efficiency is 15.4%. On the other side, Dongjiyu's average annual amount of insolation from 2007 to 2014 is approximately 1476.6kWh/m². These mean the annual power generation of PV system in Dongjiyu shall reach 109,582.6 kWh as the annual power generation per PV module goes to approximately 317.08 kWh.

3.3.2 Innovativeness

Chinese Taipei is surrounded by off-islands that require self-generating power supply. However, power instability, black-outs and high level of carbon emission have been the issues for these islands and waiting for better solution. Limited choices such as diesel generator (DG) or other isolated power supply units are used because of small-sized power system or the distance to better-equipped power provider. Meanwhile, the carbon emission from diesel generator or other independent power supply is also bring uncertainties and concerns not only because of the pollution but also the inefficiency of high cost from fuel transporting over long distance. Therefore, the importance of increasing the usage of renewable energy can't be more emphasized. It reduces the fuel use, cuts down the carbon emission significantly and eases the burden from budget limits. To optimize the overall efficiency for even better quality in power supply and to further enhance the power stability, the integration of micro-grid technology comes in and works as the solution. As it works as the foundation, it extends the application for renewable energy and trims down the overall cost even more. Reliability, stability, high quality and financial sustainability all come in one place for future development and improvement for electricity supply for off-islands.

Penghu County Government plans "Carbon-Free Island Demonstration Project – Planning and Designing." The goal is to introduce the micro-grid system in Dongjiyu. The objectives include, increasing the use of renewable energy, reducing diesel power generation, enhancing the quality of power supply in off- islands and providing low-carbon power supply. The Project includes the use of power generation forecasting for energy scheduling, remote monitoring for load forecasting, and control system for three-phase equilibrium of AC power.

(1) The Origin of this innovative technology

Power generation by renewable energy is dependent on weather, seasonal and day/night conditions, therefore, energy storage and back-up power are needed to stabilize power supply for microgrid in islands or remote regions. Meanwhile, due to the inherent intermittency of renewable energy, the power quality is inevitably affected when increased amount of renewable sources are connected to the grid, this means a real-time monitoring, control system and energy storage are therefore required to effectively dispatch and coordinate the distributed energy sources. The overall economic effectiveness of microgrid is critical to end-user market and wide adoption, accordingly, optimization of resource usage and provision of high quality power are important topics for microgrid development.

(2) Proposed technology

This application is specifically targeted to address the four microgrid issues – supply stability, power quality, economic effectiveness, and increased utilization and penetration of grid-tie renewable-based generation. Our team proposes a total solution, including microgrid design and evaluation, Smart microgrid Monitoring and Energy Management System (“Smart μ -MEMS”), the integration of Energy Storage System (ESS) and existing diesel engine power generator as a Hybrid Microgrid Solution (“Hybrid MS”).

The microgrid evaluation optimizes both sub-system and system configuration and operation requirements based on analysis from environmental and actual grid conditions. This covers the complete life-cycles of the renewable generation sources, other distributed generation and the energy storage solution deployed. Smart μ -MEMS effectively controls the scheduling of different renewable energy, other generations and energy storage systems by matching the needs of end-users. Based on real-time system operating status and information, coupled with requirements on power supply stability and power quality, Smart μ -MEMS optimizes resource allocation – both for regular use and emergency conditions. Hybrid MS, characterized by the combined Energy Storage System (ESS) and diesel generator, improves the power quality issues arising from high renewable energy penetration, PV power supply disruption or feeder lines congestion in urbanized settings.

Chung-Hsin Electric & Machinery Manufacturing Corporation (CHEM) has implemented the microgrid system project in conjunction with the Penghu County Government in Dongjiyu and implemented the project “Penghu Dongjiyu Microgrid Small Power Supply System (PDMS).” Hybrid MS is the core technology of the project. The framework of PDMS is as following:

Hybrid MS is the core technology of the project. The advantages are significant. The higher usage of renewable energy reduces the consumption of diesel fuel along with exhaust emission, especially CO₂. By cutting down the consumption of diesel fuel, it saves up to 48% of the cost

not only for diesel generators operating but maintenance (diesel cost, delivery and maintenance charges). Meanwhile, high quality and stability of off-island electricity supply is then greatly enhanced via Smart μ -MEMS. For the moment, financial support and potential investors are keen to explore more possibilities because of the positive outcome generated from utilizing Hybrid MS. This is to say that financial investment along with the government's focus on smart low-carbon power generating system, have transferred into steady and high-quality electricity use for local residents. A win-win situation for the investors, business operator, government and the residence is therefore guaranteed.

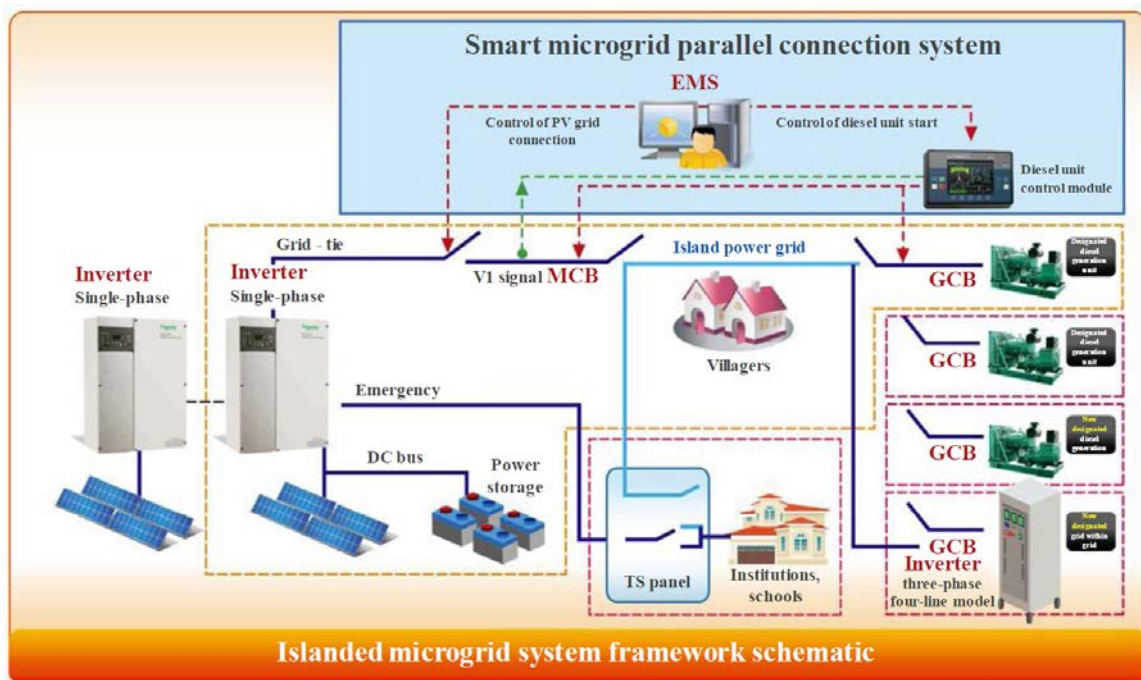


Fig. 3-3.2 Penghu Dongjiyu microgrid small-scale power supply system: Islanded microgrid system Framework

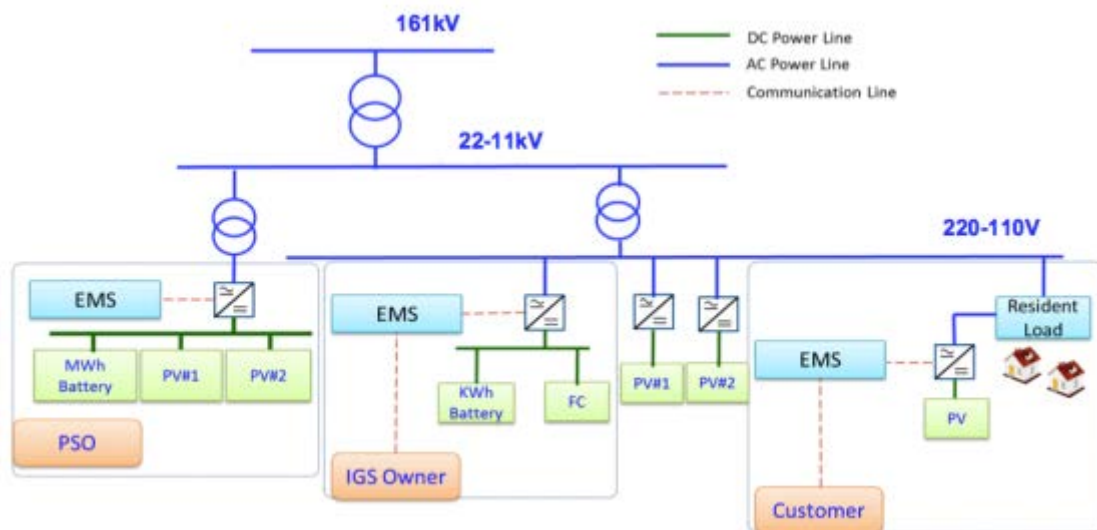


Fig. 3-3.3 Three Main Direct Potential Applications for Adoptions in Chinese Taipei's Grid

(3) Potential application

There are three main direct potential application of our proposed system for adoptions in Chinese Taipei's grid, as shown in Fig. 3-3.3. For each potential application, the PDMS will provide performance data points and the associated economic feasibility aspects that cater to Chinese Taipei's domestic needs, as illustrated clearly in table 3-1.

Table 3-1 Three Application Scenarios

Three Application Scenarios	Direct User	Technology Areas	Economic Parameters
1. Direct connection to feeder-lines	Power System Operator (PSO)	System Specification for feeder line voltage control; Communication protocols	Cost and economic feasibility for corresponding auxiliary services offered
2. Direct couple to existing solar system	Intermittent Generation Sources (IGS) Owner	Response time; Accurate control	Operational cost and economic attractiveness in Chinese Taipei's adoption
3. Direct connection on user's end (Distribution)	Customer	System operational stability	Cost comparison with grid-supplied electricity in Chinese Taipei

3.4.4 Social and economic benefit

The parameters and results of the 20-year average cost of this system are shown in uploaded file"Appendix 1-1 Levelized Cost of Electricity (LCOE).pdf." The cost details include the equipment cost, the construction cost, the fixed annual expense and the equipment replacement that has reached the end of the service life. The formula for calculating the Levelized Cost of Electricity (LCOE) is:

$$\text{LCOE} = (\text{Sum of Present Value of Annual Expenditure}) / (\text{Sum of Product of Solar Power Generation and Discount Factor})$$

According to the above-mentioned calculation results, LCOE of Dongjiyu Solar Power System with Energy Storage System is USD 0.1826/kWh.

● Off-Grid Mode	● Grid-tied Mode	● Mini Power Station
<ul style="list-style-type: none"> ➤ Rural areas ➤ No utility ➤ Islands ➤ Diesel fuel is expensive ➤ Maintenance free ➤ Larger PV and battery 	<ul style="list-style-type: none"> ➤ Urban areas ➤ Utility available/unstable ➤ High electricity price ➤ Interactive with grid ➤ Grid feed-in (optional) ➤ Smaller PV and battery 	<ul style="list-style-type: none"> ➤ Tele-communication station ➤ No utility ➤ Good power quality required ➤ Diesel generator standby ➤ Minimum maintenance ➤ Larger PV and battery





Fig. 3-3.4 Multiple Operational Areas for Application

The key driver for development of smart grid comes from the maturing energy storage technologies. The rapid declining cost of ESS is set to render and boost up the commercial readiness of massive adoption for renewable energy application and integration. Assuming similar microgrid integration schemes as PDMS can be applied in Chinese Taipei main grid system, it could potentially boost up the Intermittent Generation Sources (IGS) capacity from 4.07GW to 28.5GW, as calculated with an overall generational capacity increasing of 24.43GW in year 2025. This domestic source of clean energy of 50 GkWh amounts to an effective NTD 2.85 Trillion market-sized industry. This is essentially an effective boost for domestic GDP. Given Chinese Taipei's current huge reliance on import of energy for power generation, this can also further strengthen Chinese Taipei's energy security. Moreover, the corresponding environmental impact decreasing offered by this domestic clean energy is also significant.

3.4 “Six-in-One” Multi-distributed Renewable Energy Hybrid Project of GCL Energy Center in Suzhou, Jiangsu Province, China

3.4.1 Project overview

“Six-in-One” multi-distributed renewable energy hybrid project of GCL Energy Center is currently the largest micro grid application case in China. The project locates at GCL Energy Center of GCL China Headquarters in Suzhou city, Jiangsu province of China, and takes the Energy Center as the solid support to carry out construction and implementation.²⁶

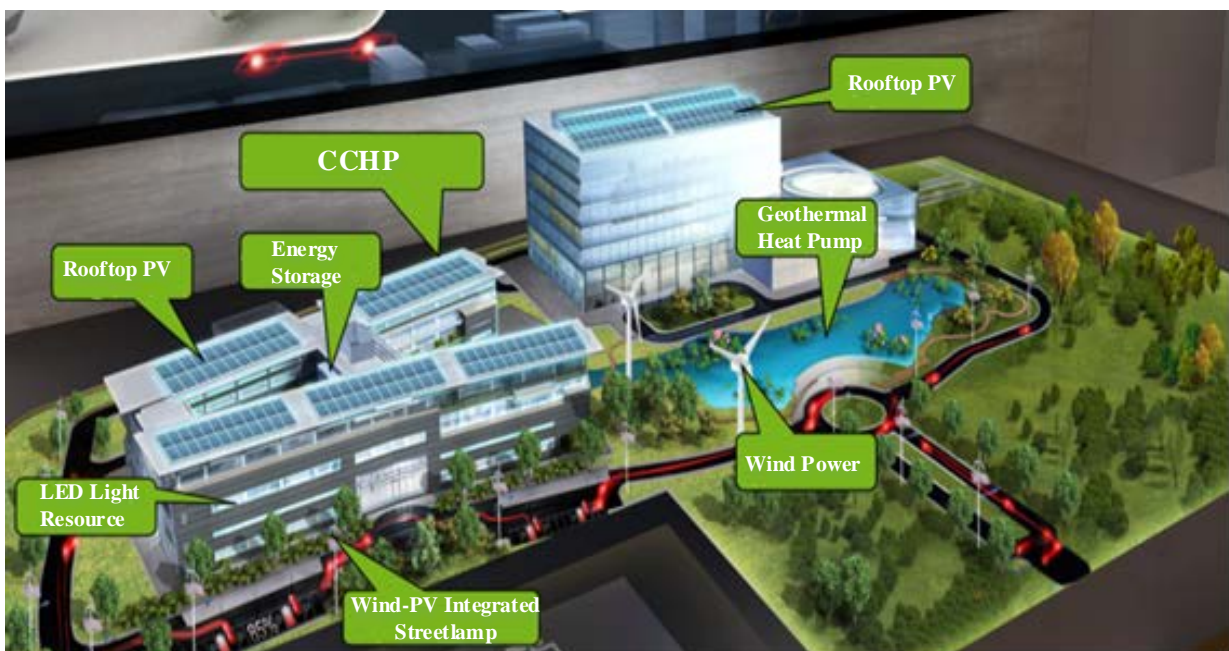


Fig. 3-4.1 Overview of “Six-in-One” Multi-distributed Renewable Energy Hybrid Project

The needs of GCL Energy Center are mainly for electricity, air-con refrigeration, heating and living water etc. The design load of total energy demand is about 3200kW, and the energy-saving design at user side saves up to 2000kW comparing with regular energy configuration. By the implementation of “Six-in-One” multi-distributed renewable energy hybrid project, the PV generation system of phase I and II can provide 808kW electric power, and the natural gas distributed combined cooling, heating and power system (CCHP) can offer 400kW electric power, 400kW heating/cooling energy; the ground-source heat pump of phase II can provide 5000kW (which equals to 980kW electric energy) heating/cooling energy; breeze generating system can provide 60kW electric power; and an energy storage system of 200kW is installed for adjusting the stability of the whole micro grid. The self-power-supply rate of the Energy

²⁶ Project information is provided by GCL Intelligent Co., Ltd.

Center is over 50% (municipal power supply will compensate the rest of the power need), and the whole building can save up to more than 30% of the energy.

“Six-in-One” multi-distributed renewable energy hybrid project is optimized designed per the need of both supply and demand side, and it distributes in all regions that the Energy Center covers in a multi-point way.

Phase I of the Energy Center: natural gas distributed combined cooling, heating and power system (CCHP)+PV power generation + energy storage + ground-source heat pump + wind-solar-energy integrated street lamps + breeze generating system + LED light source; Phase II of the Energy Center: roof PV+LED light source + ground-source heat pump+ wind-solar-energy integrated street lamps.



Fig. 3-4.2 Interface of Energy Internet Operation Cloud Platform in Suzhou Industrial Park

3.4.2 Key technologies on “Six” subsystems

The core of GCL energy micro grid lies in a comprehensive application for different kind of energies, and fully considers their distinct features to integrate them organically into the micro grid while coordinating and optimizing several kinds of energies. In the meantime, the grid offers different types of energies such as electricity, cooling, heating and gas etc. to the users to satisfy their multiple energy demand. It improves the utilizing efficiency of multi-

energy, and reduces the general cost of users' energy consumption so that the objectives like energy saving and emission reduction, and ecological environment protection are reached.

"Six-in-One" multi-distributed renewable energy hybrid project is integrated and implemented with "six" subsystems which are: natural gas distributed energy system, PV power generation system, breeze generating system, energy storage system, LED energy-saving system and micro grid monitor system. While completing the core technologies of all subsystems, it also realized a technical breakthrough on high integrated operation of multi-energy forms.

(1) Natural gas distributed energy system: the natural gas distributed energy system constructs a 400kW-level natural gas distributed combined cooling, heating and power (CCHP) energy station, and equips one set of 400kW level gas-fired combustion engine+1 unit of smoke-gas dual use lithium bromide absorption refrigerating machine set (400kW refrigerating output). By the heating-electricity-cooling co-production technology, it can provide 400kW electric power and 400kW cooling/heating energy to the Energy Center.

(2) PV power generation system: the PV power generation system mainly uses the solar battery panel made by photovoltaic effect theory to generate electric energy. This project takes advantage of office building roof and car shed to install PV power generation system.

(3) Breeze generating system: the breeze generating system fully uses the wind power in the energy central area, and can start generation when the wind speed reaches 2.8m/s. The installed breeze generating system has an installed capacity of 60kW, among which the horizontal-shaft wind generates 50kW power and the vertical-shaft wind generates 10kW power.

(4) Energy storage system: energy storage system is part of the micro grid system. It is composed of lithium iron phosphate battery, ESMU, ESBMS, system group unit control and ESGU. The system capacity is 200kWh.

(5) LED energy-saving system: office and manufacturing regions of GCL Energy Center all adopt GCL LED light source which is totally 135kW. There are 4kW of wind-solar-energy storage and charging which equals to regular light source and can save 30% energy consumption.

(6) Micro grid monitor system: the establishment of micro grid monitor system realized a multiple advancing adjustment which includes: prioritize low-carbon dispatch, prioritize PV and wind, store extra energy; match power source side dispatch with user side need, decrease peak-shaving on load; energy efficiency dispatch, use heating to determine electricity; explore

research on interference-resisting ability for the micro grid to accumulate experience on demonstration and promotion.

3.4.3 Project characteristics

GCL “Six-in-one” micro grid has six characteristics as energy generation, green energy, multi-energy, energy storage, energy saving and micro energy:

- **Energy generation:** takes advantages of renewable and abandoned energy to create usable heating, electricity and cooling energy. Optimize transforming model for the using energies.
- **Multi-energy:** both the originating and supply forms of energy realize the full use and integrated application of multi-energy to ensure safe and reliable energy utilization.
- **Green energy:** all energies that are used are zero or slight emission (solar power, wind energy, natural gas). Ecological environmental protection, green and low carbon.
- **Energy saving:** it achieves the gradient utilization of energy and greatly reduces energy consumption; adopts green energy-using device, improves using efficiency; intelligent energy-saving.
- **Energy storage:** it enables storage-supply integration; absorbs and buffers the system fluctuation; peak-shaving; improves system stability.
- **Micro energy:** lower the production unit of energy to KW level and can provide unique energy solution for every small user.

GCL “Six-in-One” multi-distributed renewable energy hybrid project achieves breakthrough on 4 technologies: peak-shaving, low grade heating energy utilization, energy storage and micro energy grid.

“Six-in-One” multi-distributed renewable energy hybrid project achieves a three-dimensional integration for renewable and new energies. It fully elaborate the advantage of multi-energy forms, provides a multi-energy supply grid, guarantees the safety of energy consumption, and solves 4 technical issues as: storage of energy consumption, peak-shaving, low grade heating energy utilization and micro power grid. Micro grid and its devices have strong automatic control capability, convenient start-stop. They also can change the load from zero to full grade in a short time to offer an energy supply in a modern method nearby the load center, with which can match the peak-valley difference of the load center randomly; low grade heating energy utilization technology solves the energy peak-shaving problem. It uses technologies like ground-source heat pump and power generation by hot water to put the low-

temperature energy, which is below 80°C, into the consumption of high-level energies (electric power or steam) reducing from refrigeration, power generation and heat making, and achieves the heating source transfer from low-temperature to high-temperature.

3.4.4 Social and economic benefit

The total investment of the “Six-in-One” multi-distributed renewable energy hybrid project is about 40 million RMB. The whole micro grid industrial chain is currently in a rather high cost stage. Therefore, national and local government of China allows building up pilot and demonstration project by approval within a scope where the resource condition and devices are rather mature, and would give a 10%-20% subsidy. Besides, the electric power generated from the PV system will have a 0.42 yuan/kWh extra subsidy per degree from the government so that a fast development of micro grid industrial chain can be facilitated.

3.5 APEC ESCI Best Practices Awards: Smart Integrated Energy Microgrid in Customer Service Center of State Grid Corporation of China

3.5.1 Project overview

This project won APEC ESCI Best Practices Awards: 2019 Silver Award of Smart Grid²⁷.

Customer Service Center (CSC) is responsible for providing online customer services for the service area of State Grid Corporation of China (SGCC), which covers 26 provinces and affects over 1.1 billion people. It provides a 24-hour all year service for individual and enterprise users including blackout notice, customer information inquiries, business consultation, and business processing. CSC has two parks, the Northern Customer Service Center (NCSC) and Southern Customer Service Center (SCSC). NCSC, located in Tianjin, has a total construction area of 143,000 square meters. SCSC, located in Nanjing, has a total construction area of 136,000 square meters. NCSC and SCSC can accommodate 5200 employees' working and living. As a result of high population density and working schedule, the variety and high-level of energy demands pose new challenges for energy supply solutions of electricity, heat, cooling, and hot water. Thus, a Smart Integrated Energy Microgrid (SIEM) is built in CSC. The energy facilities of SIEM include ground source heat pump, ice storage system, electric boiler with heat storage, solar water heating system, photovoltaic system, and electric distribution networks. Moreover, a control and energy management platform is developed to realize the intelligent coordinated dispatching of SIEM. The various demand of the park could be met with a lower operation cost and more environment-friendly way.



Fig. 3-5.1 Smart Integrated Energy Microgrid in CSC

²⁷ Project information is provided by State Grid Corporation of China .

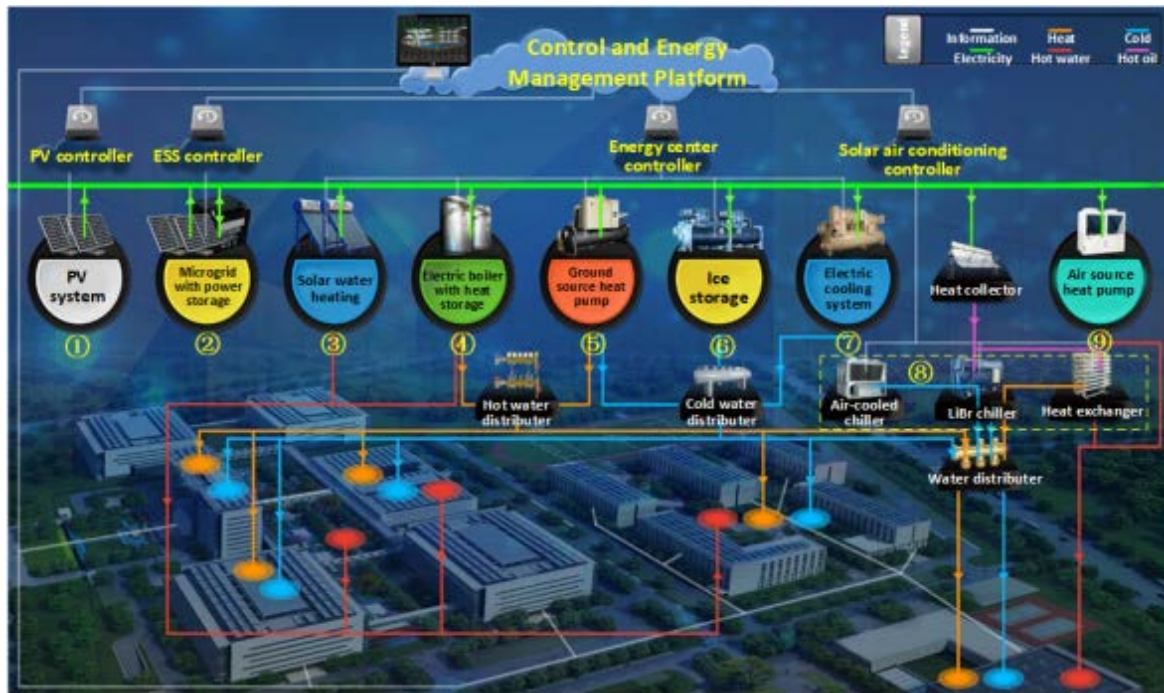


Fig. 3-5.2 Structure of SIEM in NCSC of Tianjin

Table 3-2 Capacities of Energy Subsystems

Energy subsystem	SCSC	NCSC
Photovoltaic system	1009 kWp	823 kWp
Ground source heat pump	Cooling: 4900 kW Heating: 4922 kW	Cooling: 3690 kW Heating: 4065 kW
Solar water heating system	1411 kW	1007 kW
Solar air conditioning system	/	Cooling: 350 kW Heating: 210 kW
Wind power generation system	80kW	/
Air source heat pump	1932 kW	216 kW
Ice storage system	Icing: 7737 kW Cooling: 5416 kW	Icing: 6328 kW Cooling: 4680 kW
Electric boiler with heat storage	6568 kW	8200 kW
Microgrid with power storage	50 kW*4 h	50 kW*4 h
Electric cooling system	2461 kW	6328 kW

The pilot project, SIEM in CSC of Tianjin, has been successfully built in Tianjin and Nanjing. It realizes efficient utilization of solar energy, air thermal energy and geothermal energy to feed the park. The energy subsystems include photovoltaic system, ground source heat pump system, solar hot water system, solar air conditioning system, air source heat pump, wind power generation system, ice storage system, heat storage electric boiler system, and energy storage microgrid. The structure of the system is shown in Fig. 3-5.2. The capacities of energy subsystems are given in Table 3-2.

3.5.2 Innovativeness

To replace the traditional fossil fuel with renewable energy and substantially increase the energy efficiency, it is necessary to set up a new frame of energy infrastructure which is more clean, safe and efficient. For this purpose, an electricity-based SIEM that integrates multiple energy resources is established (as shown in Fig. 3-5.3). The brain of SIEM, a control and energy management platform, is proposed and constructed, which can effectively coordinate and optimize the production, transmission, distribution, storage, and consumption of the involved energies. This work has been applied and tested in CSC. The pilot project shows that the new concept and technologies can effectively increase the penetration of renewable energy in customer-side energy consumption and the energy efficiency through coordination and optimization.

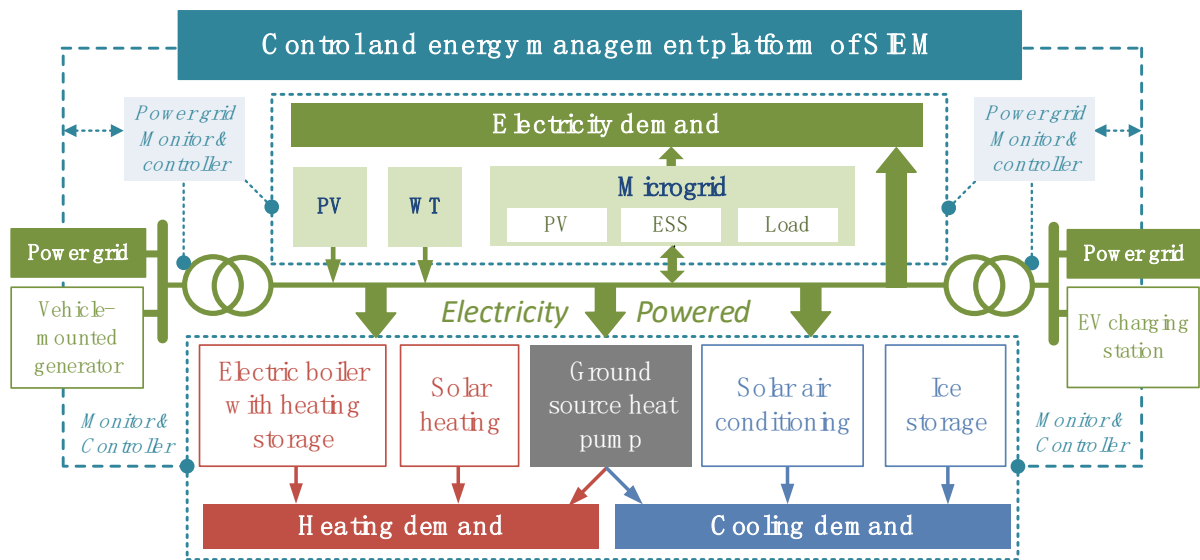


Fig. 3-5.3 Frame of SIEM

The innovative ideas and technologies of SIEM are that each kind of energy is coupled with electricity, the latter is the core of the energy production, conversion, storage, and consumption. A series of novel methods, including the modeling, planning, energy management, evaluation of the multi-energy system, are proposed.

(1) Theoretical innovation

The concept of “energy bus” on system modeling is proposed (as shown in Fig. 3-5.4). The energy relationship among all equipment in SIEM can be accurately expressed and calculated, which facilitates the standardization and scalability of energy system modeling and analysis.

A multi-objective based optimization strategy considering multi-energy coordinated management is proposed combining day-ahead and real-time scheduling (as shown in Fig. 3-5.5). It improves the flexibility of the system to deal with various uncertain energy demand and realizes intelligent dispatching of SIEM.

Evaluation indexes and method for SIEM are proposed to provide an objective and quantifiable foundation for system planning and operation. The method consists the indexes from four categories, including region, subsystem, equipment and environment.

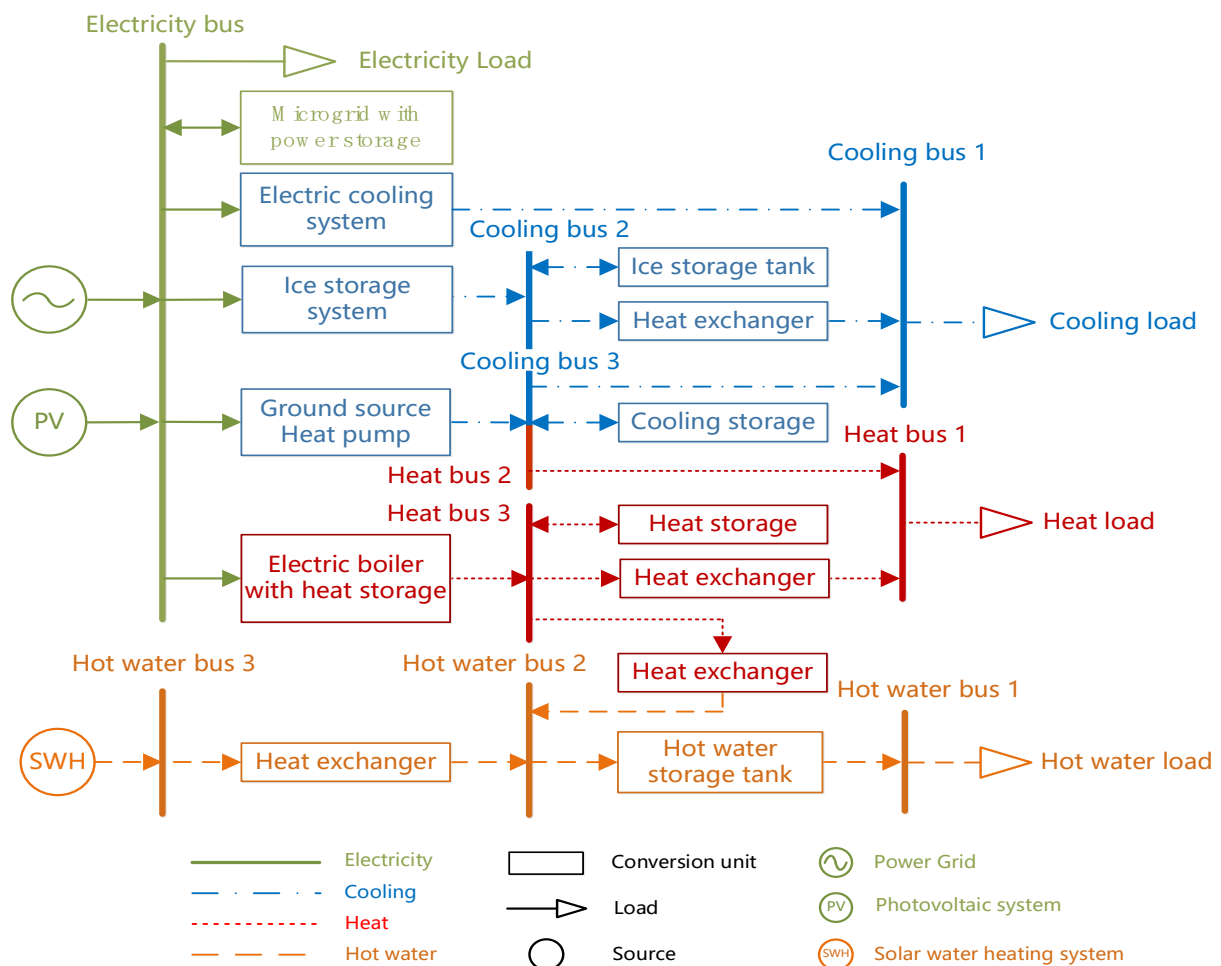


Fig. 3-5.4 Energy Bus Structure of SIEM

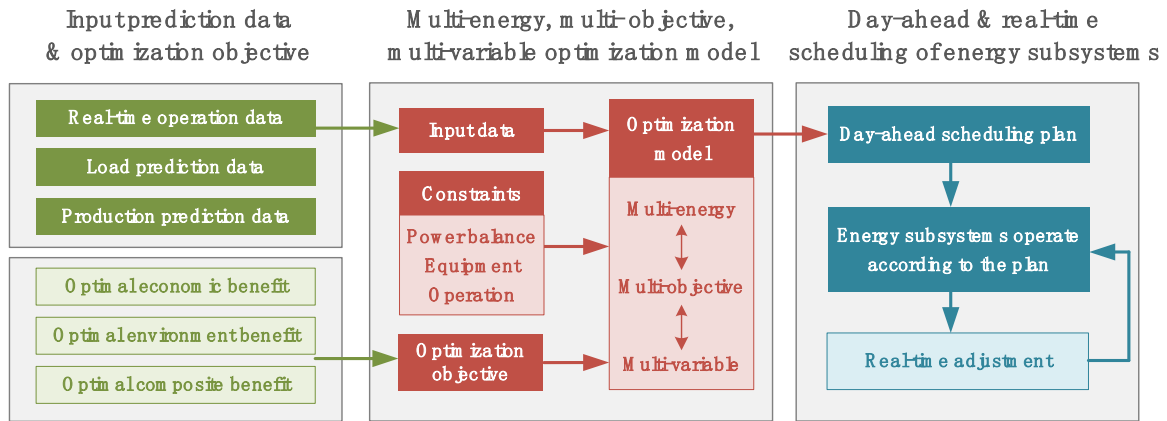


Fig. 3-5.5 Optimization Strategy of SIEM

(2) Technical innovation

A planning tool for SIEM is developed to realize the standardized modeling and optimal siting and sizing of the energy equipment in SIEM. It can provide optimized energy supply solutions for various situations with multi-energy demand.

A control and energy management platform is developed to realize the intelligent coordinated dispatching of SIEM. It improves the penetration of renewable energy and meets the demand for electricity, cooling, and heat with a lower cost of operation.

Technological and economic evaluation is continuously performed to provide suggestions for system maintenance and upgrade through post-evaluation.

(3) Business innovation

A new business model using electricity as the core of energy conversion and transaction is proposed. It realizes a unified criterion for the operation and management of SIEM. Thus, energy suppliers can provide integrated energy solutions and value-added services for the customer.

The application of the technologies and methods innovated in this project provides new ideas and solutions for the energy system update and new construction. The proposed business model can provide mutual experiences and win-win strategies for all the stakeholders including investors, operators, government, and users. It has a promising prospect in seeking financial support from energy enterprises, users or third-party enterprises

3.5.3 Social and economic benefit

(1) Cost-effectiveness

The energy facilities of this project include ground source heat pump, ice storage system, electric boiler with heat storage, solar water heating system, photovoltaic system, and electric distribution networks.

The total construction investment is 187.02 million CNY.

If conventional energy supply scheme is adopted, the construction investment of municipal heating, chiller units, electric heating system and electric distribution networks is 126.64 million CNY.

The construction investment of SIEM is 60.38 million higher than conventional energy supply scheme.

The cost of annual energy purchase of SIEM is 10.07 million CNY, which is only the cost of electricity supply, as a result of the heating is completely covered by the system. The operation and maintenance cost is 2.4 million CNY. The annual income of photovoltaic system is 2.24 million CNY. The annual benefit of the control and energy management platform is 1.28 million CNY, the detailed calculation is shown in 3). Thus, the total operation cost of SIEM is 8.95 million CNY per year.

If conventional energy supply scheme is adopted, the annual energy purchase cost (including electricity and heating supply costs) is about 18.47 million CNY and the annual operation cost is 1.2 million CNY. The total operation cost is 19.67 million CNY per year.

The operation cost of SIEM is 10.72 million CNY lower than the conventional scheme every year.

Smart integrated energy microgrid platform has been more convenient by using control strategy.

The control and energy management platform can realize precise control of the balance of energy supply and consumption, which is more accurate and efficient than the manual scheduling strategy. In the cooling season, the operating cost is 4.21 million CNY, which is 0.39 million yuan lower than the manual scheduling strategy (4.6 million CNY), a decrease of 8.4%. In the heating season, the operation cost is 6.98 million CNY, which is 0.9 million yuan lower than the manual scheduling strategy (7.88 million yuan), a decrease of 11.4%. In summary, the control and energy management platform can reduce the operating cost by 1.28 million CNY per year with a decrease of 10.4%.

Comparing with the conventional energy supply scheme, the construction investment of SIEM is 60.38 million CNY higher, but the operation cost is 10.72 million CNY lower.

As a result, the payback period for the increased construction investment is about $60.38/10.72=5.63$ years.

(2) Significant change in the field of energy efficiency and energy saving

SIEM can significantly save energy and improve energy efficiency through integrating distributed energy resources and using energy management strategies such as peak load shifting, optimal scheduling, and coordinated control. In 2016-2018, the average penetration of renewable energy was higher than 32%, and the highest level is 64.17%. More than 80% of the cooling and heat was provided by renewable energy. Photovoltaic generation accounts for more than 5% of the total power consumption. The operation cost was reduced by 10.72 million CNY per year on average, 32.17 million CNY in total. The implementation of the project has effectively improved the environmental benefits, which is of excellent demonstration effect on energy conservation and emission reduction.

The technical solution proposed by this project can be widely applied in various situations with multi-energy demand, including industrial parks, cities, airports, railway stations, hospitals, and schools. This project was first put into operation in Tianjin and a similar system is being built in Nanjing in 2017. Although there are differences in energy utilization models between northern and southern China. It is an integrated energy solution for most of APEC grid and off-grid areas, most of the key technologies of this project are still effective and can be easily applied in multiple operational areas.

3.6 Tesla 100MW Energy Storage project in Australian

3.6.1 Project overview

Tesla built a 100MW/129MWh lithium battery energy storage system next to the Hornsdale wind farm in South Australia. The energy storage project was put into operation on December 1, 2017, and it is the largest battery energy storage system that has been put into operation²⁸. The core component of the energy storage is the PowerPack energy storage unit, which jointly establish "Hornsdale Power Reserve (HPR)".



Fig. 3-6.1 Tesla 100MW Energy Storage

The Hornsdale Wind Farm consists 105 wind turbines with 315 MW output. As the wind accounts for one-third of the total power mix within the South Australia state, there is a need to secure the grid with some reserves. The HPR reserves 70 MW of its discharge capacity for designated system security services contracted with the South Australian Government. The remaining 30 MW power capacity and 119 MWh energy storage is available to Neoen for market participation²⁹. The battery will provide frequency and ancillary services to the grid, as well as storing energy from the wind farm, “firm” its supply contracts with commercial and industrial customers³⁰.

²⁸ H. Zeng et al. Introduction of Australian 100MW Storage Operation and its Enlightenment to China, 2018 China International Conference on Electricity Distribution (CICED), Tianjin, 2018, pp. 2895-2900.

²⁹ Hornsdale Power Reserve Impact Study [EB/OL]. <https://www.aurecongroup.com/markets/energy/hornsdale-power-reserve-impact-study>

³⁰ Giles Parkinson. Tesla big battery at Lake Bonney wind farm faces connection delays [EB/OL]. <https://reneweconomy.com.au/tesla-big-battery-at-lake-bonney-wind-farm-faces-connection-delays-23158/>



Fig. 3-6.2 Hornsdale Wind Farm

3.6.2 Key technologies

(1) Tesla PowerPack

Powerpacks, the core component of energy storage in the HPR project, use a high volume, high reliability architecture tested over the one billion miles driven in Model S. Every Powerpack contains 16 individual battery pods, each with an isolated DC-DC converter. Pod architecture and onboard power electronics optimize performance across the array and enable easy swapping at any time. Combined with hundreds of embedded sensors, Powerpack offers unparalleled performance, safety and reliability. An internal liquid cooling and heating system allows for pinpoint temperature control within a Powerpack³¹.

Tesla PowerPack contains two battery modules, and integrates the battery management system, heat management system and independent board DC/DC. Each battery pack capacity is 13.5kWh, the nominal voltage is 48V. It is converted to 350V-550V through DC/DC. Each battery unit can be independently charged and discharged to achieve 2-4 hours of continuous charge and discharge. Tesla's energy storage converter control module can provide 3 control modes: (1) controllable current source mode; (2) virtual synchronous mode; (3) mixed mode .

- In the current source mode, the inverter can provide 0-100% controllable current variation in 4ms;
- In the virtual synchronous mode, the inverter provides moment of inertia,

³¹ https://www.tesla.com/en_AU/powerpack?redirect=no

voltage/frequency stability and harmonic control;

- In the mixed mode, the synchronous compensator/synchronous generator characteristics will be synchronized and closed. The three modes can be switched smoothly.



Fig. 3-6.3 Tesla PowerPack³²

(2) Hornsdale Power Reserve Network Loading Control Ancillary Services

The HPR is included in a new control scheme – the System Integrity Protection Scheme (SIPS) – which is intended to reduce the likelihood of the South Australia power system separating from the rest of the National Electricity Market following a sudden increase in flow on the Heywood Interconnector. The SIPS control scheme is intended to detect high flows on the Heywood Interconnector and trigger the HPR to start discharging at 100 MW as quickly as possible³³.

HPR is an integral element of the SIPS, which protects the Heywood interconnector from tripping due to extreme import flows, thereby reducing the risk of separation of South Australian from the National Electricity Market and a system black event. The SIPS incorporates three progressive stages, the first of which is a fast response trigger to inject energy from battery energy storage systems, and HPR is a key participant in this stage of the SIPS. Upon receipt of a signal from ElectraNet, HPR will discharge up to 100 MW output in less than

³² https://www.tesla.com/en_AU/powerpack?redirect=no

³³ Initial operation of the Hornsdale Power Reserve Battery Energy Storage System [EB/OL].
<http://www.aemo.com.au/Media-Centre/AEMO-Hornsdale-report>.

150 ms. This will potentially prevent activation of the next stage of the scheme, which involves load shedding in South Australia. In a hypothetical contingency event, HPR assist in maintaining the South Australian network frequency at above 49 Hz, which is the point at which under-frequency load shedding is activated. Without HPR's contribution, the frequency is modelled to fall to approximately 48.7 Hz, in which case load shedding would be required to arrest the falling frequency.

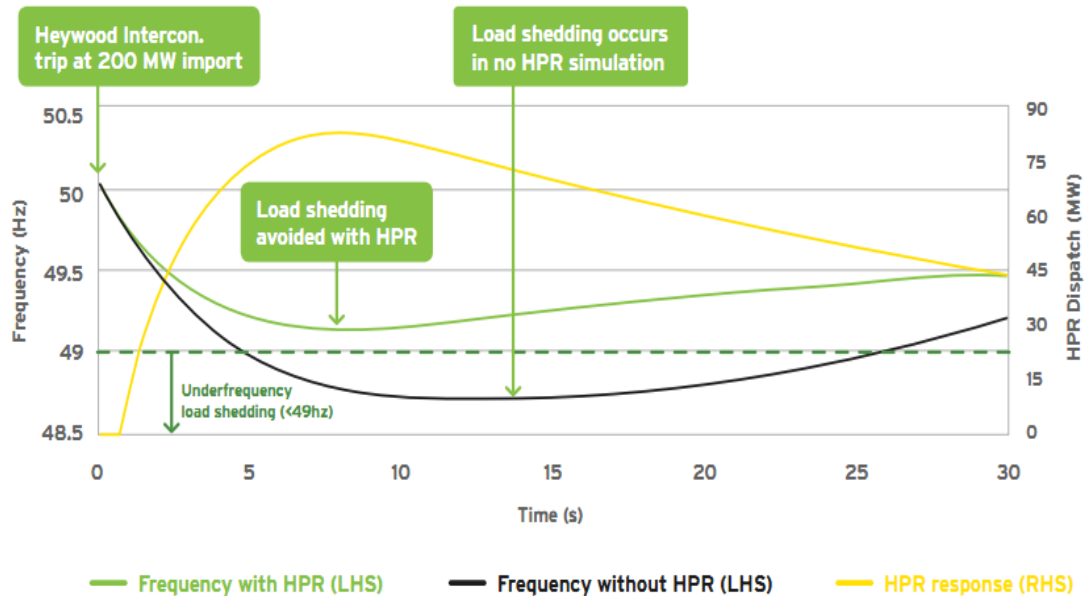
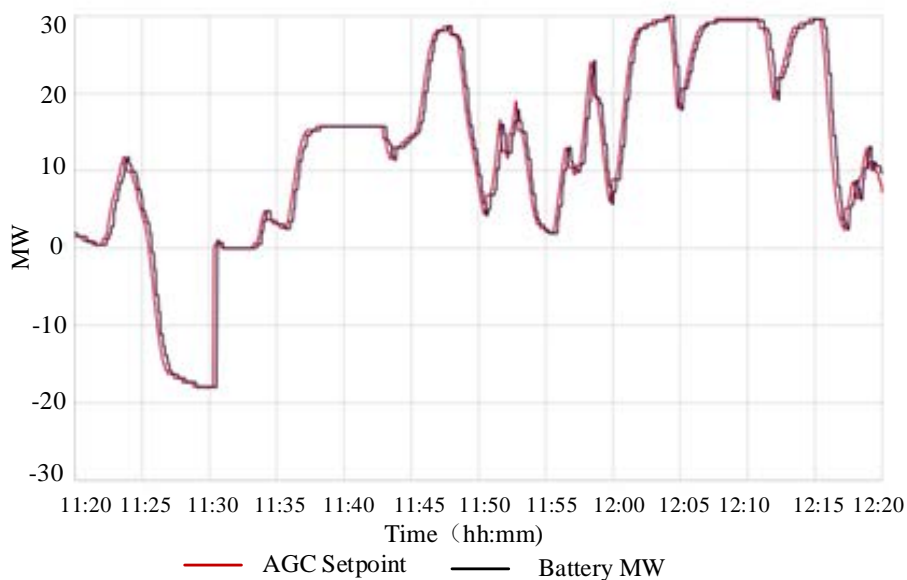


Fig. 3-6.4 Hornsdale Power Reserve Response during frequency disturbance³⁴



³⁴ Hornsdale Power Reserve Impact Study [EB/OL]. <https://www.aurecongroup.com/markets/energy/hornsdale-power-reserve-impact-study>

Fig. 3-6.5 HPR Accuracy and speed of regulation FCAS response³⁵

(3) Hornsdale Power Reserve Frequency Control Ancillary Service (FCAS)

Automatic Generation Control (AGC) system can be used to control the HPR, and this is the normal control arrangement most of the time. AGC control send a new MW set-point to the battery at a rate of up to once every four seconds. This enables the HPR to provide regulation FCAS in South Australia. Operational data shows that HPR provides very rapid and precise response to regulation FCAS signals. This is in contrast to large conventional steam turbines, which can lag the AGC signal by up to several minutes.

3.6.3 Characteristic of the Project

This project provide a world-leading battery storage facility to stabilize the South Australian electricity grid, facilitate integration of renewable energy and assist in preventing load-shedding events. The characteristic of the project can be concluded as follows:

(1) Hornsdale Power Reserve, which contains lots of Tesla PowerPack, at 100MW/129MWh, is the largest lithium-ion battery in the world. Southern Australia has lots of wind during windy hours and lots of sun during sunny hours. However, when neither wind nor sun is available the grid lacks energy and the grid operator has to re-dispatch generation capacity to keep his grid stable. In December, 2017, for the first time, clean and affordable wind energy could be stored and dispatched to the grid 24 hours a day, 7 days a week, whether the wind is blowing or not, always maintaining grid stability³⁶.

(2) Hornsdale Power Reserve can provide Frequency Control Ancillary Service (FCAS). FCAS is needed to maintain the frequency of the power system within the operating standards, and is called upon by the Australian Energy Market Operator to cope with planned and unplanned network outages, particularly the Heywood inter-connector that links South Australia and Victoria³⁷.

³⁵ Initial operation of the Hornsdale Power Reserve Battery Energy Storage System [EB/OL].
<http://www.aemo.com.au/Media-Centre/AEMO-Hornsdale-report>.

³⁶ <https://new.siemens.com/global/en/products/energy/references/transformer-for-largest-storage-battery.html>.

³⁷ <https://reneweconomy.com.au/how-teslas-big-battery-can-smash-australias-energy-cartel-64548>

Chapter IV: Demand Potential and Promotion Suggestions of Integrated Multi-energy System in APEC Region

4.1 Energy supply and demand of APEC

4.1.1 Primary energy supply and final energy consumption of APEC

The Asia-Pacific Economic Cooperation (APEC) is a group of 21 economies located in the Asia-Pacific region that are dedicated to achieving a shared prosperity through economic growth and free trade. The forum was formed in 1989 as an informal dialogue among government officials from 12 economies. Since then, its membership and scope has expanded to 21 economies. The member economies are home to around 2.9 billion people. In 2017, APEC accounted for 60% of gross domestic product (GDP) and 47% of the world trade³⁸³⁹.

According to the International Renewable Energy Agency (IRENA), the world total primary energy supply and final energy consumption were 13081 Mtoe and 9556 Mtoe in 2016 respectively⁴⁰⁴¹. The total primary energy supply and final energy consumption of APEC were 7891.81 Mtoe and 4736.61 Mtoe in 2016, which accounting for 60.3% and 50.0% of the world respectively (Fig. 4-1). From 1990 to 2016, primary energy supply and final energy consumption increased rapidly in APEC region resulted from the rapid economic growth, with an average annual growth rate of about 2.5% and 2.1% respectively. Coal, oil and natural gas are the dominant primary energy, accounting for 35.4%, 29.5% and 21.7% in 2016 respectively. Coal, oil, natural gas and electricity are the dominant final energy consumption, accounting for 16.4%, 35.4%, 14.9% and 24.3% in 2016 respectively. Coal supply and consumption peaked in 2011 and then began to decline. Renewable energy (RE) and electricity in both primary energy supply and in final energy have been an upward trend, with an average annual growth rate of about 4.3% and 4.8% respectively during 1990-2016. But the share of RE is still far below fossil energy, which is less than 8% by the end of 2016.

³⁸ APEC Secretariat (2019), APEC at a Glance 2019, Available via <https://www.apec.org/Publications/2019/02/APEC-at-a-Glance-2019>

³⁹ APEC Energy Database (2019) APEC Energy Working Group EGEDA. <https://www.egeda.ewg.apec.org/>. Accessed 2019

⁴⁰ Key World Energy Statistics (2019) IEA. <https://www.iea.org/statistics/kwes/supply/>. Accessed 2019

⁴¹ Key World Energy Statistics (2019) IEA. <https://www.iea.org/statistics/kwes/consumption/>. Accessed 2019

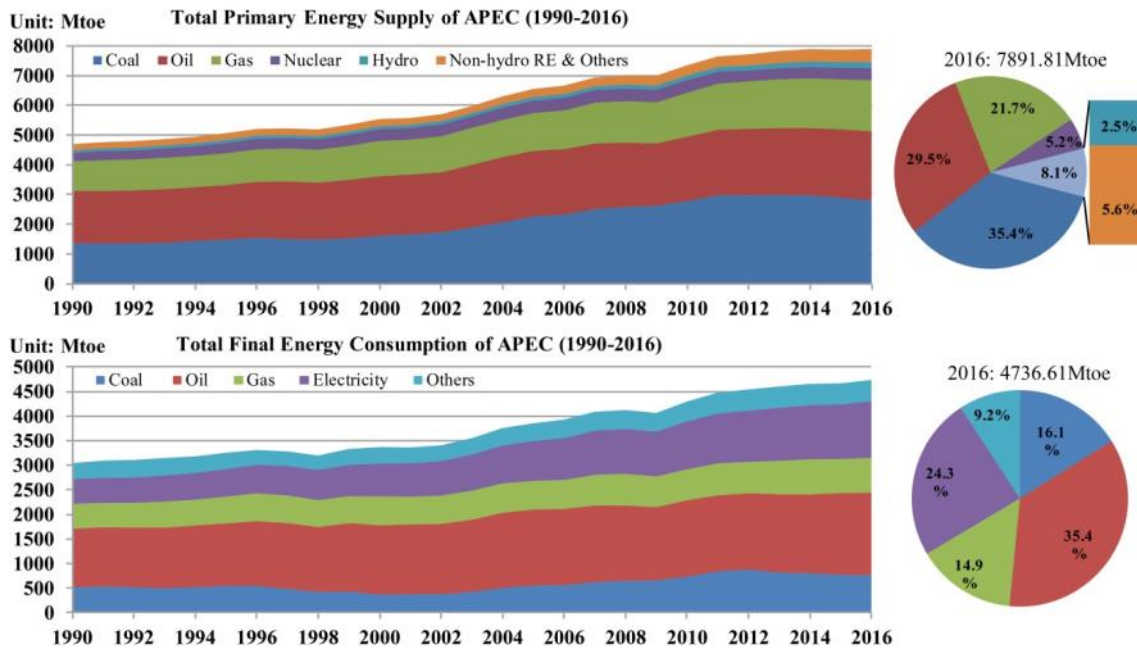


Fig. 4-1 Total primary energy supply and final energy consumption of APEC (1990-2016)

China, United States, Russia and Japan are the top four energy supply and demand economies (Fig. 4-2), accounting for 36.5%, 27.5%, 9.3%, 5.4% in total primary energy supply and 36.7%, 29.4%, 8.2%, 5.5% in total final energy consumption in 2016 respectively.

As for primary energy supply, six economies' share of coal is above 25%, including China (65.6%); Hong Kong, China (46.5%); Viet Nam (40.2%); Chinese Taipei (34.1%); Australia (33.7%); Korea (28.9%) and Japan (27.4%). Except for Viet Nam (28.1%), Hong Kong, China (25.8%), Russia (23.7%), China (19.0%), and Brunei Darussalam (15.9%), other economies' share of oil is above 30%. Ten economies' share of nature gas is above 25%, including Brunei Darussalam (84.1%), Russia (50.7%), Mexico (35.7%), Malaysia (34.8%), Canada (33.8%), Singapore (32.0%), Peru (31.2%), United States (30.1%), Thailand (29.8%) and Australia (26.6%). Only nine economies' share of RE in primary energy supply is above 10%, including New Zealand (41.6%), Philippines (36.9%), Indonesia (28.0%), Chile (27.1%), Peru (21.1%), Thailand (20.2%), Viet Nam (19.5%), Canada (17.5%) and Papua New Guinea (14.1%).

As for final energy consumption, ten economies' share of electricity is above 25%, including Hong Kong, China (55.8%); Chinese Taipei (42.5%); Singapore (37.5%); Korea (34.5%); Brunei Darussalam (32.8%); Japan (32.0%); Malaysia (27.3%); Viet Nam (26.8%); New Zealand (25.4%), and China (25.3%), Indonesia has the lowest share of electricity, only 12.1%. Oil is the main type of final energy, except for China (23.8%) and Russia (22.4%), other economies' share of oil is above 30%. Ten economies' share of nature gas is above 25%, including Russia (30.1%), Canada (25.4%), United States (23.0%), Korea (16.7%), Australia

(16.2%), New Zealand (12.8%), Malaysia(12.1%), Mexico (11.8%), Japan (11.1%), Singapore (10.5%). Four economies' share of coal is above 10%, including China (37.4%), Viet Nam (22.8%), Chinese Taipei (15.9%) and Japan (12.4%).

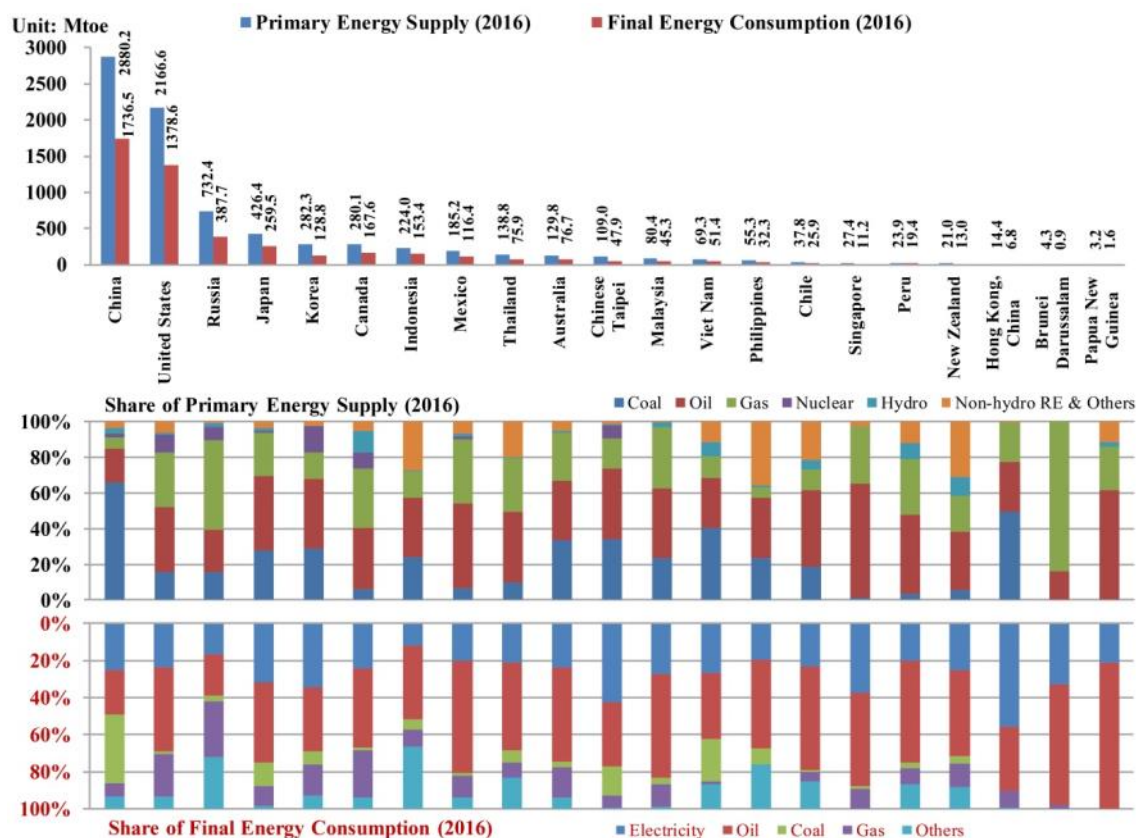


Fig. 4-2 Primary energy supply and final energy consumption of APEC economies by fuel (2016)

4.1.2 Electricity supply and demand of APEC

(1) Electricity generating capacity and generation

According to IEA, the world total electricity generation were 25082 TWh in 2016⁴². The total electricity generating capacity and generation of APEC were 4019.15 GW and 15791.04 TWh in 2016 (Fig. 4-3), and the electricity generation accounting for 63.0% of the world. From 2006 to 2016, electricity generating capacity and generation increased rapidly in APEC region, with an average annual growth rate of about 3.3% and 4.9% respectively.

Thermal power is the biggest part of electricity generation, in which coal and oil accounting for 47.2% and 21.8% in 2016 respectively, and its share grows slowly. Nuclear

⁴² Key World Energy Statistics (2019) IEA. <https://www.iea.org/statistics/electricity/>. Accessed 2019

power is declining, its share is 10.0% in electricity generation in 2016. RE is growing rapidly, and its share in electricity generation in 2016 is about 20%. Non-hydro RE has the fastest growing, with an average annual growth rate of about 117.7% and 29.7% in electricity generating capacity and generation respectively during 2006-2016.

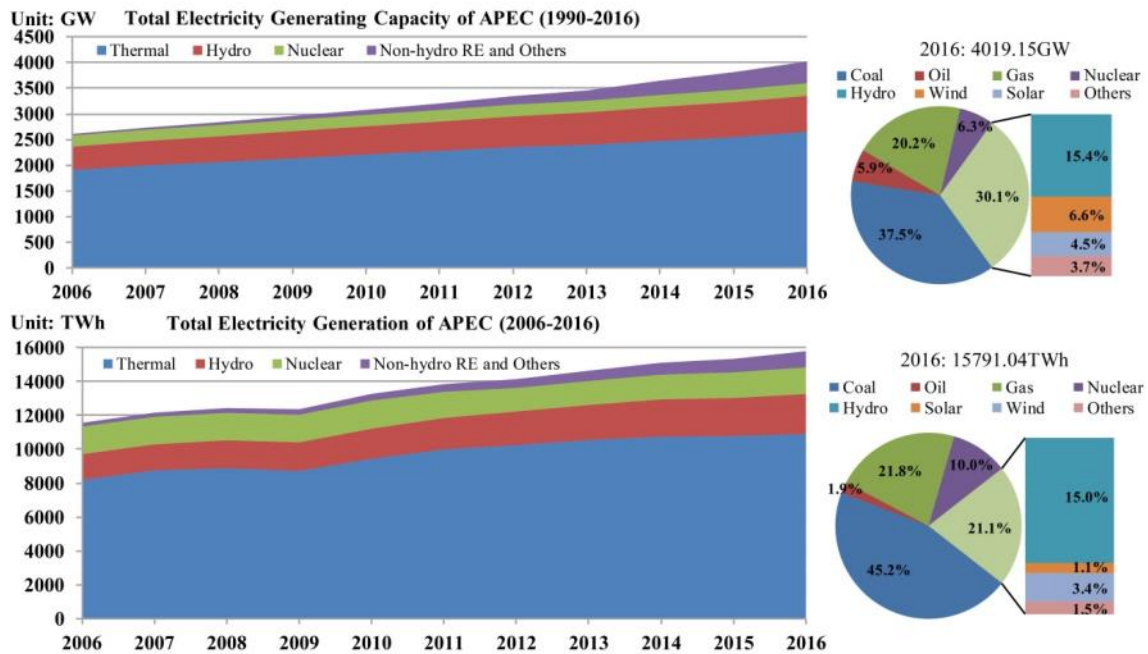


Fig. 4-3 Total electricity generating capacity and generation of APEC by fuel (2006-2016)

China, United States, Japan and Russia are the top four electricity consumption economies (Fig. 4-4), accounting for 38.9%, 27.2%, 6.7%, 6.9% in total electricity generating capacity and 41.0%, 27.2%, 7.5%, 6.4% in total electricity generation in 2016 respectively.

As for electricity generating capacity, except for Canada (24.4%) and New Zealand (23.9%), other economies' share of thermal power is above 55%. Six economies' share of hydro power is above 25%, including New Zealand (57.5%), Canada (55.7%), Viet Nam (43.1%), Peru (37.0%), Papua New Guinea (29.0%) and Chile (27.1%). Only eight economies have nuclear power, including Korea (20.8%), Japan (3.9%), Chinese Taipei (10.3%), Russia (10.2%), Canada (9.7%), United States (9.1%), Mexico (2.2%), and China (2.0%). Eight economies' share of non-hydro RE is above 10%, including Indonesia (19.9%), New Zealand (18.6%), Philippines (15.6%), Australia (13.8%), China (13.6%), Thailand (12.6%), United States (11.0%) and Canada (10.2%).

As for electricity generation, coal and natural gas are the dominant electricity generation, more than half economies's share of coal-fired power generation or gas-fired power generation is above 30%. Nine economies' share of hydro power is above 10%, including New Zealand (59.87%), Canada (58.02%), Peru (46.51%), Viet Nam (35.44%), Chile (29.35%), Papua New

Guinea (22.61%), China (19.43%), Russia (16.95%) and Malaysia (12.78%). Although non-hydro RE developed very fast in recent years, its share is still very low. Only seven economies' share of wind power is above 3%, including New Zealand (5.36%), United States (5.34%), Australia (4.76%), Canada (4.61%), China (3.86%), Mexico (3.24%) and Chile (3.09%). Only two economies' share of solar power is above 3%, including Japan (3.84%) and Chile (3.33%). Only four economies' share of geothermal power is above 3%, including New Zealand (17.28%), Philippines (12.19%), Papua New Guinea (9.45%) and Indonesia (4.30%).

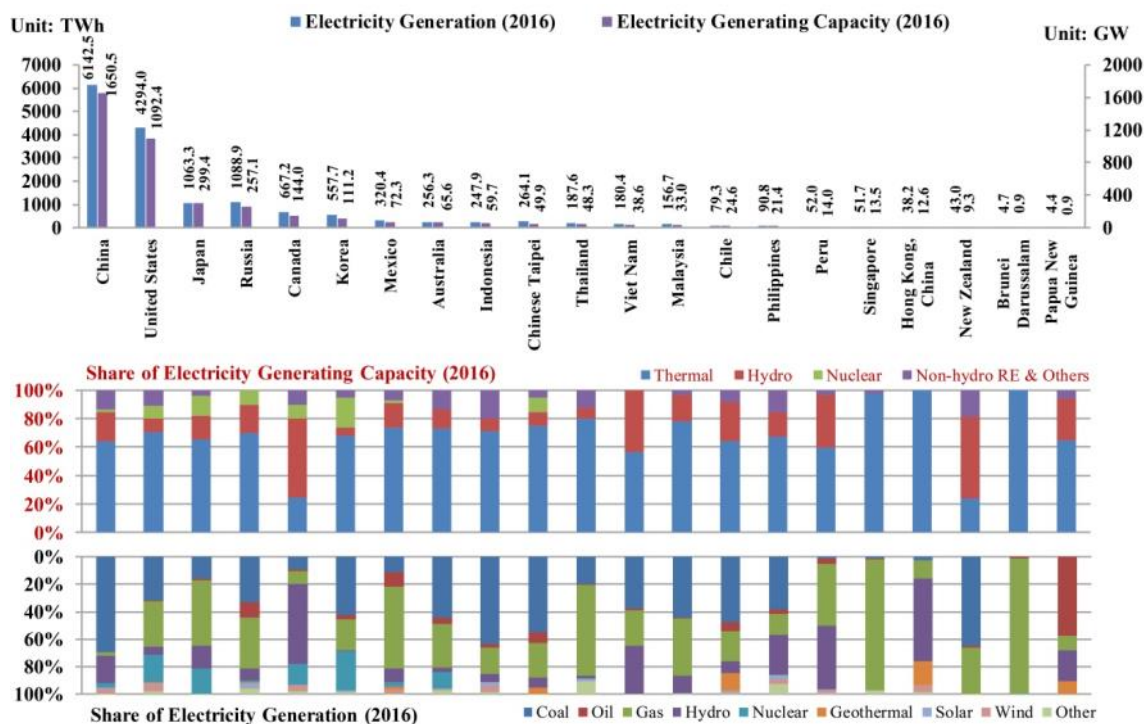


Fig. 4-4 Electricity generating capacity and generation of APEC economies by fuel (2016)

(2) Electricity consumption by end-use sector

Industry, transport and building (including commerce and public services, and residential) are three main sectors in final energy consumption (Fig. 4-5), accounting for about 39.0%, 29.5%, and 26.6% in 2016 respectively. But transport is not main sector for electricity consumption, its share is only 2.0%. Industry, commerce and public services, and residential accounts for about 45.5%, 20.4% and 25.4% of electricity consumption in 2016 respectively. Industry sector has the largest share of electricity consumption and has a trend of increase.

Seven economies' electricity is consumed by industry sector with share of above 50% (Fig. 4-6), including China (65.73%), Chile (62.16%), Peru (60.15%), Chinese Taipei (57.38%), Mexico (53.98%), Viet Nam (53.81%) and Korea (51.30%). Twelve economies' share of building sector is more than 50%, including Brunei Darussalam (95.00%), Hong Kong, China

(92.64%), United States (72.75%), Indonesia (68.35%), Philippines (63.92%), Australia (59.72%), Canada (58.96%), Thailand (58.12%), Japan (57.51%), New Zealand (56.67%), Singapore (55.01%) and Malaysia (52.41%).

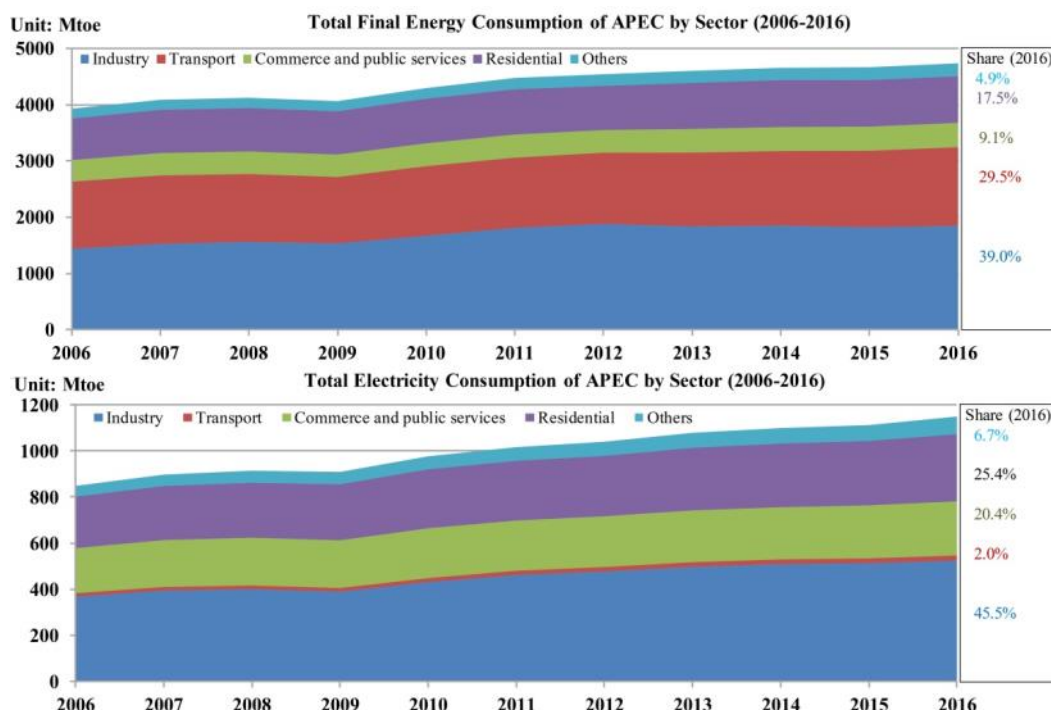


Fig. 4-5 Total final energy and electricity consumption of APEC by sector (2006-2016)

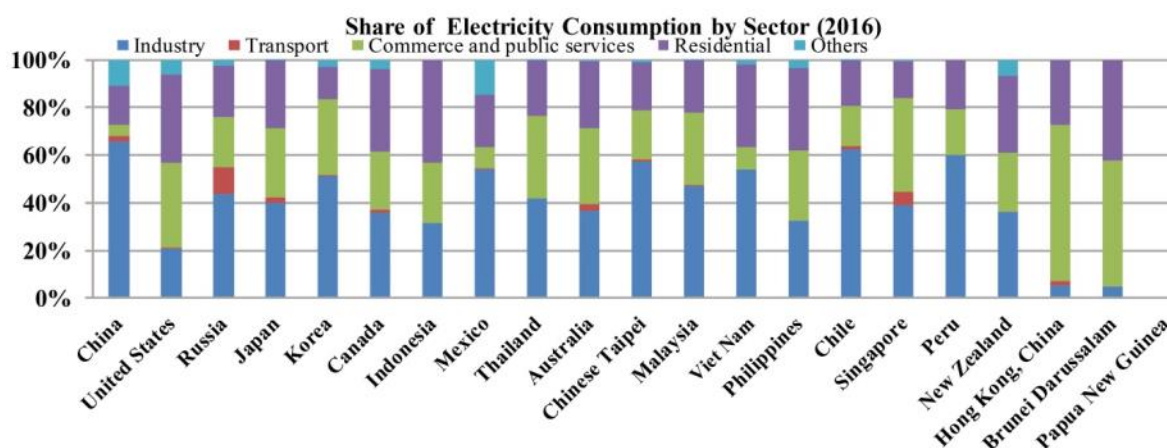


Fig. 4-6 Share of electricity consumption of APEC economies by sector (2016)

(3) Access to electricity

The 21 APEC member economies have different levels and stages of development, as a result part of the population in some economies is not yet electrified. According to statistics of World Bank, there are still four APEC economies' access to electricity has not yet reached 100%

by the end of 2017, the total population without access to electricity is 16.93 million (Fig. 4-7)⁴³.

Particularly Papua New Guinea, its access to electricity is only 54.43%, the corresponding population without access to electricity is about 3.68 million. The other three economies are Philippines (93.00%), Peru (96.36%), and Indonesia (98.14%), the corresponding population without access to electricity is about 7.23, 1.16 and 4.86 millions.

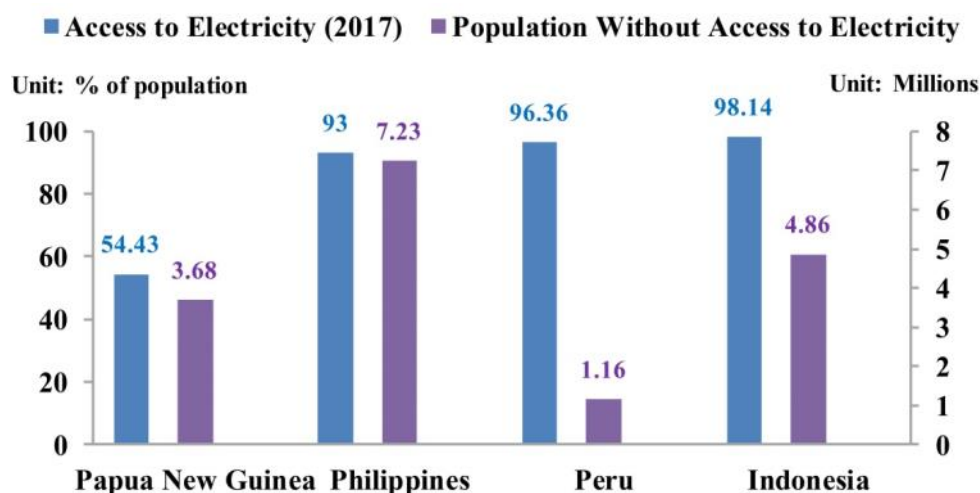


Fig. 4-7 Access to electricity of APEC economies (2017)

(4) Annual per capita electricity consumption

According to United Nations and IEA, the world average annual per capita electricity generation and GDP were 3360.4 kWh and 10665.0 USD in 2016 respectively. The corresponding value of APEC were 5500.7 kWh and 15791.0 USD in 2016 respectively, which were about 1.5 times of world average (Fig. 4-8)^{44,45,46}.

The annual per capita electricity consumption is positive proportional to the annual per capita GDP. Six economies' annual per capita electricity generation is more than 10000 kWh, including Canada (18397.9 kWh), United States (13291.2 kWh), Chinese Taipei (11231.0 kWh), Brunei Darussalam (11212.3 kWh), Korea (10882.3 kWh) and Australia (10595.7 kWh),

⁴³ World Bank Open Data (2019) World Bank. <https://data.worldbank.org/indicator>. Accessed 2019

⁴⁴ Key Indicators Database (2019) APEC. http://statistics.apec.org/index.php/apec_psu/index. Accessed 2019

⁴⁵ UN Data (2019) United Nations Statistics Division. <http://data.un.org/>. Accessed 2019

⁴⁶ United Nations (2019), World Population Prospects 2019, Available

the corresponding annual per capita GDP is more than 20000 USD, far beyond world and APEC average.

Seven economies' annual per capita electricity generation is less than world average, including Thailand (2724.8 kWh), Mexico (2511.8 kWh), Viet Nam (1907.1 kWh), Peru (1635.6 kWh), Indonesia (949.5 kWh), Philippines (878.8 kWh) and Papua New Guinea (549.8 kWh), the corresponding annual per capita GDP is far bellow world and APEC average. Particularly Papua New Guinea, Philippines, Indonesia and Peru, their annual per capita electricity is less than half of the world average.

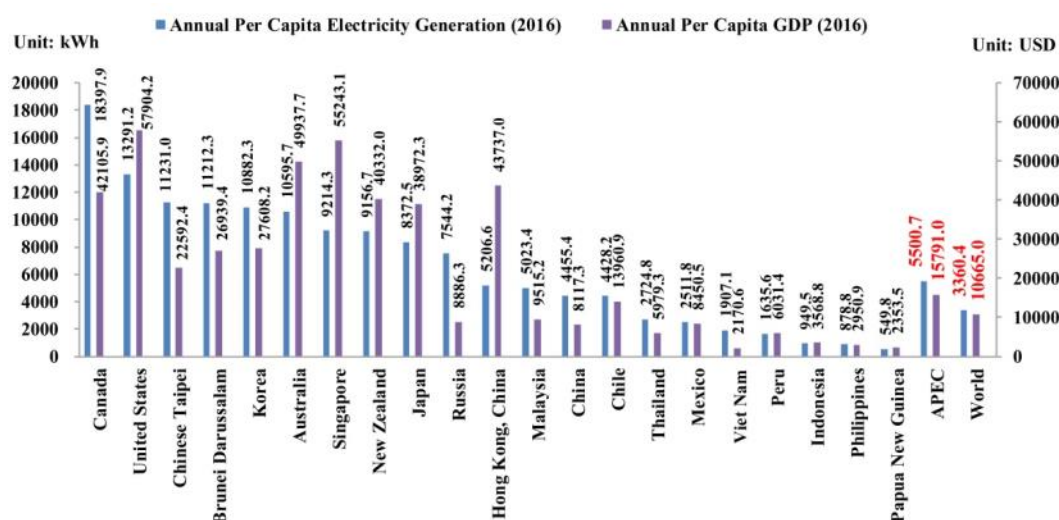


Fig. 4-8 Annual per capita electricity generation and GDP of APEC economies (2016)

4.1.3 Trends of renewable energy and electricity generation in APEC

(1) APEC targets doubling of renewable energy

To keep pace with rising demand and ease the environmental impact of economic development across the Asia-Pacific, in 2014, APEC Energy Ministerial Meeting, APEC targets of “doubling the share of renewables in the APEC energy mix, including in power generation, from 2010 levels by 2030.” was proposed⁴⁷. According to the 57th APEC Energy Working Group Meeting⁴⁸, the RE share in primary energy supply increased from 4.80% in 2010 to 6.29% in 2016, the RE share increased only 1.49 percentage points from 2010 to 2016, just 31.1% of the way to the goal. The RE share in final energy consumption increased from

⁴⁷ APEC Meeting Document Database (2019) APEC. http://mddb.apcec.org/Documents/2014/MM/EMM/14_emm11_jms.pdf. Accessed 2019

⁴⁸ APEC Meeting Document Database (2019) APEC. <http://mddb.apcec.org/Pages/searchgroupmeeting.aspx>. Accessed 2019

6.17% in 2010 to 7.79% in 2016, the RE share increased only 1.62 percentage points from 2010 to 2016, just 26.3% of the way to the goal. To reach the APEC renewable energy doubling target, the APEC economies need to accelerate RE development.

Table 4-1 Selected APEC renewable energy policies⁴⁹

Economy	Most influential policy framework	Renewable energy target in power
Australia	Australia's Renewable Energy Target (2001)	33 TWh by 2020
Brunei Darussalam	Energy White Paper (2014)	10% of generation by 2035
Canada	Pan-Canadian Framework on Clean Growth and Climate Change (2016)	-
Chile	Energy 2050 (2015); Energy Roadmap (2015)	Minimum of 60% by 2035 and 70% by 2050
China	13th Five-Year Plan, 2016-2020	15% by 2020 and 20% by 2030 in final energy mix
Hong Kong, China	Future Fuel Mix for Electricity Generation Consultation Document (2015)	Fuel mix 1% (2023)
Indonesia	Presidential Regulation 22/2017 General Plan of National Energy (2015-50)	Renewables electricity as a share of TPES: 11% in 2025 and 17% in 2050
Japan	4th Strategic Energy Plan (2014); Long-term Energy Supply and Demand Outlook (2015)	22%–24% of generation by 2030
Korea	4th National Basic Plan for New and Renewable Energy (2014); 8th Electricity Demand and Supply Basic Plan (2017)	20% generation and 34% capacity by 2030
Malaysia	National Renewable Energy Policy and Action Plan (2009); Renewable Energy Act(2011); Sustainable Energy Development Authority Act (2011); 11th Malaysia Plan (2016-2020); National Biofuel Policy (2006)	7.8% of generation and 11% of capacity by 2020, 17% of generation by 2030, and 21 GW of capacity by 2050
Mexico	Mexico's Energy Transition Law (2015)	At least 35% of generation by 2024 and 50% by 2050
New Zealand	New Zealand Energy Strategy 2011-2021; National Policy Statement for Renewable Electricity Generation (2011); Climate Change Response (Emissions Trading) Amendment Act 2008	90% of generation by 2025
Papua New Guinea	Vision 2050 (2009)	100% of generation by 2050
Peru	Legislative Decree No. 1002	Reach 5% share (excluding large hydro) by 2023
Philippines	Renewable Energy Act (2008); Biofuels Roadmap 2017-2040; Biofuels Act (2006)	20 GW of capacity by 2040
Russia	The Basic Directions of a State Policy of Renewable Energy Utilisation up to 2020 (2009); Energy Strategy 2030 (2009)	4%-6% (excluding large hydro) of generation by 2030
Singapore	Handbook for PV Systems (2011); White Paper on Renewable Energy (2014)	PV reaches ~4.5% of peak electricity demand (350 MWp) by 2020
Chinese Taipei	Renewable Energy Development Act (2009); New Energy Policy (2016)	20% of generation by 2025
Thailand	Alternative Energy Development Plan 2015-2036 (AEDP)	30% of generation by 2036
United States	US Energy Independence and Security Act (2007); RPS: 29 states + Washington, DC + 3 territories, RPG: 8 states and 1 territory	RPS up to 100% (2045 in Hawaii); 50% (2030 in California, New York, New Jersey); 50% (2040 in Oregon)
Viet Nam	Renewable Energy Development Strategy (2015); Biofuels Development Scheme (2007) and Roadmap (2017)	38% of generation by 2020, 32% by 2030 and 43% by 2050

Table 4-1 summaries the RE policies and RE target in power of all 21 APEC economies. Thirteen economies proposed target with RE share above 10% in power, including Brunei

⁴⁹ APERC (2019), APEC Energy Outlook 7th Edition Vol I. Available via <https://aperc.iecej.or.jp/publications/reports/>.

Darussalam, Chile, China, Indonesia, Japan, Korea, Malaysia, Mexico, New Zealand, Papua New Guinea, Chinese Taipei, Thailand and Viet Nam.

(2) Renewable power generation cost

Table 4-2 shows the global weighted-average electricity cost and installed cost of renewable power.

The costs for renewable energy technologies reached new lows in 2018 again 2017. Hydro power is an extremely attractive renewable technology due to the low-cost of the electricity and the flexibility it can provide to the grid, and its electricity cost is 0.047 USD/kWh in 2018, 11% lower than in 2017.

Solar photovoltaic (PV) and onshore wind power are on the verge of costing less than the marginal operating cost of existing coal-fired plants, the corresponding electricity cost is 0.085 and 0.056 USD/kWh in 2018 respectively, 13% lower than in 2017.

The cost of electricity from both geothermal and offshore wind projects declined slightly, which is around 1%. The electricity cost and installed cost of Concentrated Solar Power (CSP) declined by 26% and 28% in 2018 with the biggest drop, but it's still the most costly renewable power. Steadily improving competitiveness has made renewables the backbone of the world's energy transformation.

Table 4-2 The global weighted-average electricity cost and installed cost of renewable power in 2018⁵⁰

Renewable Power	Electricity Cost	Change of	Installed Cost	Change of installed
	(USD/kWh)	Electricity Cost	(USD/kW)	Cost
	2018	2017-2018	2018	2017-2018
Bioenergy	0.062	-14%	--	--
Geothermal	0.072	-1%	--	--
Hydro	0.047	-11%	--	--
Solar PV	0.085	-13%	1210	-13%
CSP	0.185	-26%	5204	-28%
Offshore wind	0.127	-1%	4353	-6%
Onshore wind	0.056	-13%	1497	-6%

(3) Primary energy supply of APEC by 2030

⁵⁰]International Renewable Energy Agency (2019) Renewable Power Generations Costs in 2018, Available via <https://www.irena.org/publications>

According to scenario analysis by Asia Pacific Energy Research Centre (APEREC)⁵¹, under business-as-usual (BAU) scenario, APEC target (TGT) scenario and 2-degrees celsius (2DC) scenario, the primary energy supply of APEC by 2030 will reach 8927.8, 8282.1 and 7585.2 Mtoe. In the three scenarios, coal, oil and nature gas are still the dominant primary energy supply, accounting. The total share of fossil energy will be not less than 75% (Fig. 4-9).

In TGT scenario, the net additions of primary energy supply will mainly comes from RE, nature gas and nuclear, compared with 2016 the predicted net growth is about 495, 260 and 126 Mtoe respectively. The supply of coil and oil is predicted to reduce about 463 and 75 Mtoe respectively (Fig. 4-10).

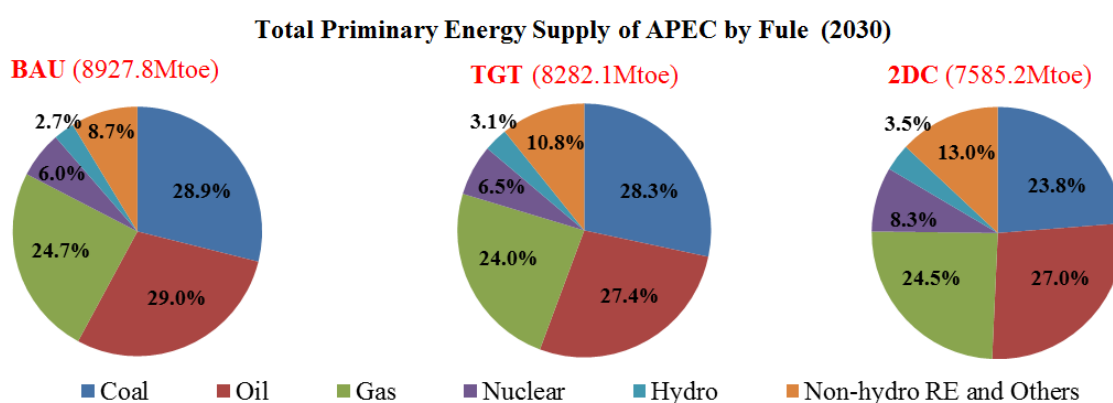


Fig. 4-9 Primary energy supply of APEC (2030) in BAU, TGT and 2DC scenarios

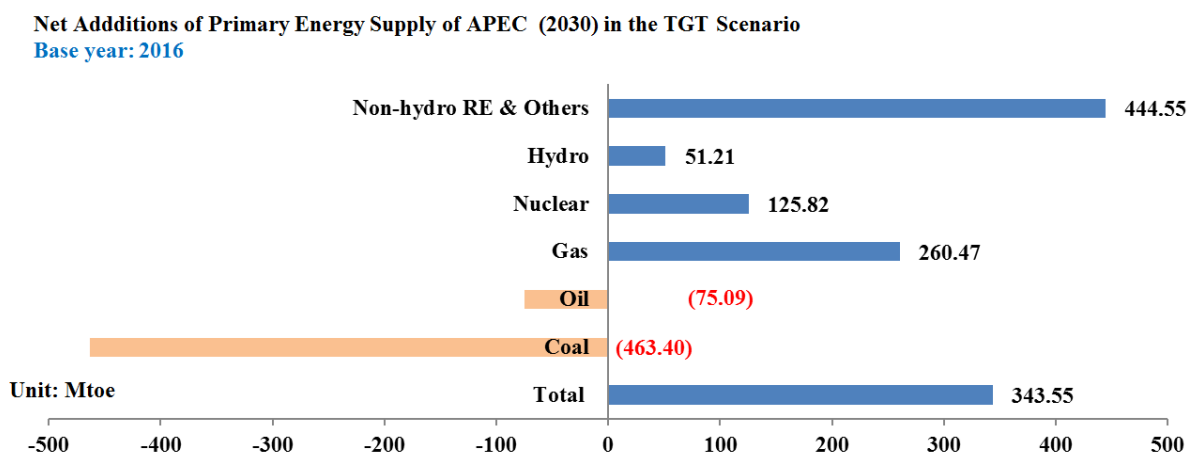


Fig. 4-10 Net additions of primary energy supply of APEC (2030) in the TGT scenario

⁵¹ APERC (2019), APEC Energy Outlook 7th Edition Vol I. Available via <https://aperc.ieej.or.jp/publications/reports/>.

(4) Electricity generation of APEC by 2030

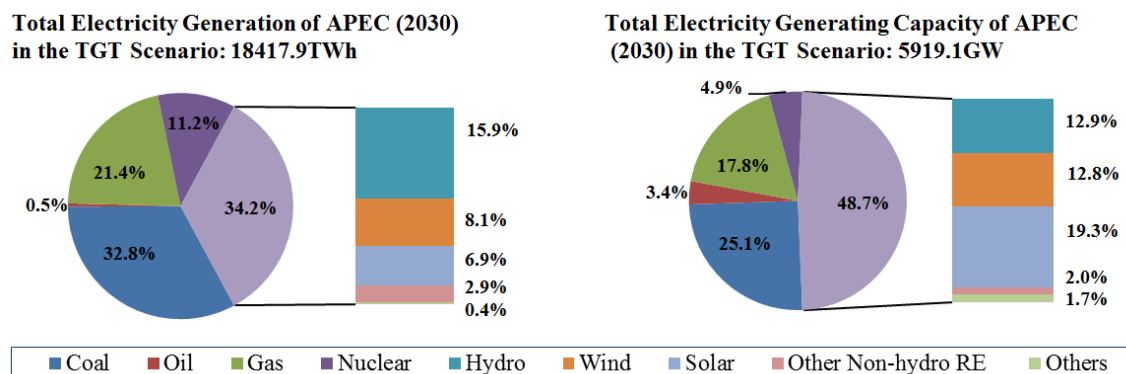


Fig. 4-11 Electricity generation and generating capacity of APEC (2030) in the TGT scenario

In TGT scenario, the Electricity generation and generating capacity of APEC by 2030 will reach to 18417.9 TWh and 5919.1 GW by 2030, increased by 17% and 47% respectively compared with 2016. Share of RE is predicted to accounting for about 34% in Electricity generation and 48% in electricity generating capacity respectively (Fig. 4-11).

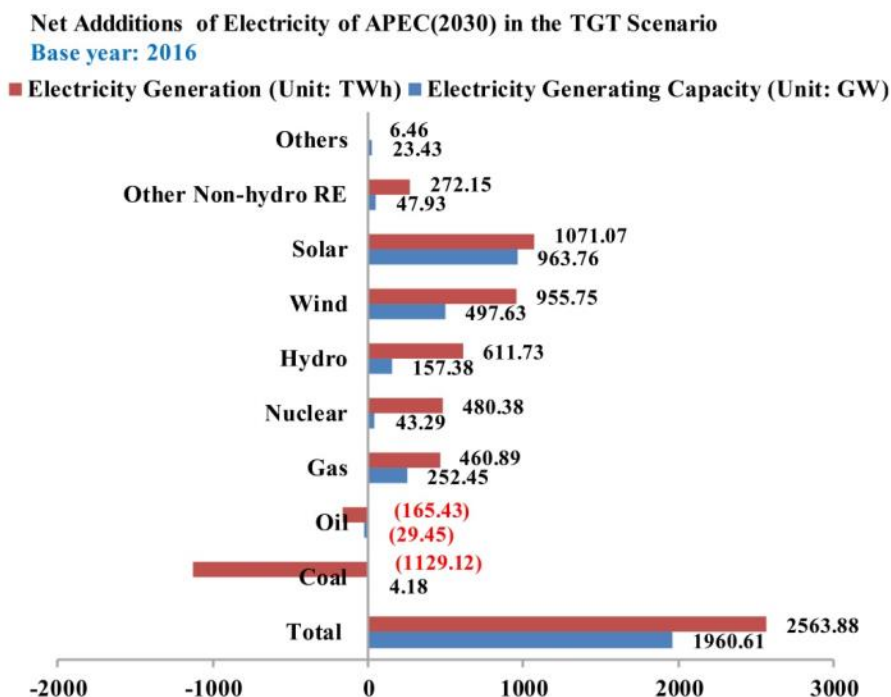


Fig. 4-12 Net additions of electricity of APEC (2030) in the TGT scenario

In TGT scenario, the net additions of electricity generation capacity will mainly comes from solar, wind, hydro, and nature gas, compared with 2016 the predicted net growth is about 963, 497, 157, and 252 GW respectively. Coal-fired and oil-fired power generating capacity will hardly changed, but the utilization hour will decline, and as a result the electricity

generation by coal and by oil will have a net decrease of about 1129 and 165 TWh respectively (Fig. 4-12).

4.2 Promotion suggestions of Integrated Multi-energy System in

APEC Region

(1) Forge a common understanding on the integrated multi-energy system in the APEC regions.

An inconsistent understanding on the connotation and characteristics for the integrated multi-energy system would inhibit the technical communication on this system in the APEC regions. Facilitating the theories of the integrated multi-energy system, standardizing and specifying the technologies and forming a common understanding are the preconditions to promote the integrated multi-energy technology in APEC regions.

(2) Carry out capability building activity based on practical experience of intergrated multi-energy projects

In order to deeply advance the technical output and cooperation on integrated multi-energy projects among APEC economies, based on project experience on integrated multi-energy and through active cooperation with relevant economies, governmental departments and companies should work together to implement a series of experience introduction and technical training in APEC regions, share experience on developing policy and technical practice on the integrated multi-energy, facilitate talent communication in related fields and build a experience-communicating system that achieves win-win cooperation.

(3) Set promoting roadmap for integrated multi-energy technology

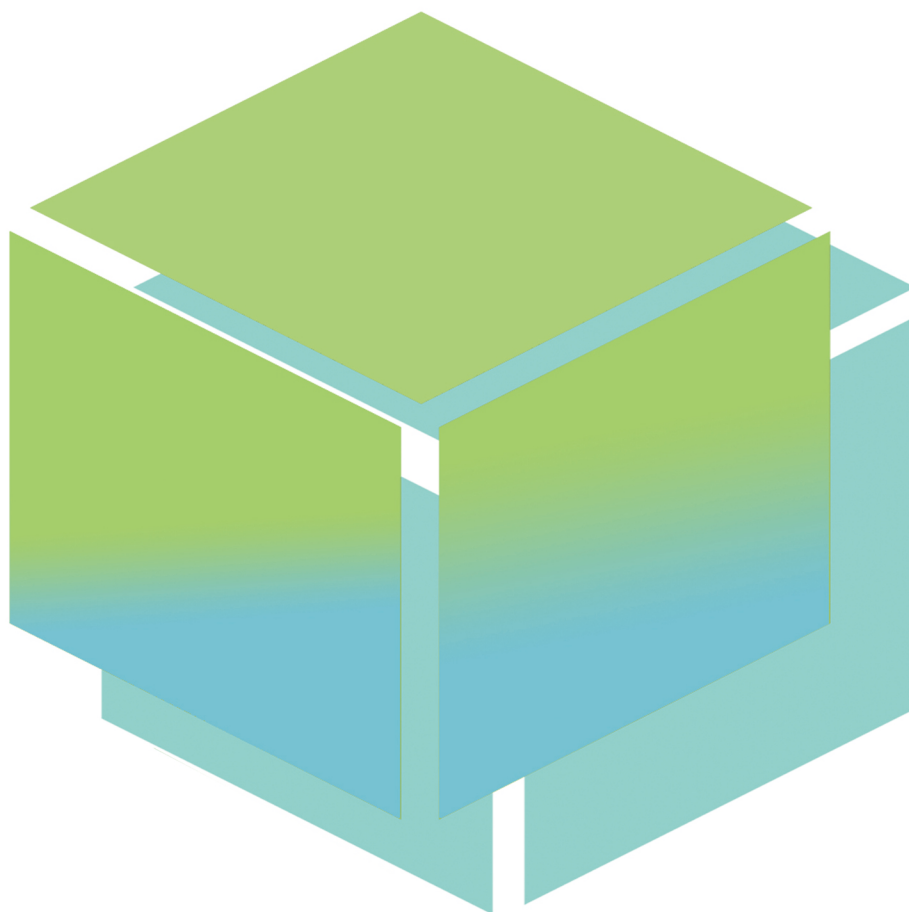
The objective of potential technical results of “integrated multi-energy” is highly conjunct with “Double-growth Plan of Renewable energies” in APEC regions. Setting a feasible planning on “promoting roadmap for integrated multi-energy technology” has a critical meaning for both promotion and guidance aspect for implementing integrated multi-energy projects in APEC regions. Actions such as recognizing economies and technical fields that can preferentially or potentially cooperate with, specifying the key technology and promotion list of “integrated multi-energy” and exploring business model on “integrated multi-energy” projects which is practical and mutually win-win, should be taken within the APEC economies.

(4) Discuss business model on integrated multi-energy development along with green financing proposal

In the developing process, the integrated multi-energy projects can combine with innovative new policy, tools and products of green financing to explore an innovative feasible and mutual win-win business model. It is fully based on market advantages to promote the coordinating development of integrated multi-energy industry in the APEC economies, to pertinently combine with relevant green financing proposal of APEC regions, to widen financing channels that can cooperate with, and to explore the new path and measures of integrated multi-energy development within the region.

(5) Rational reaction upon risk factors in the process of integrated multi-energy development

There are three possible types of risk that an integrated multi-energy may face in the developing process: policy risk, investment risk and technical risk. APEC region involves quite many economies with different social economic level, resource condition and developing principles. In the developing process of integrated multi-energy, risk factors such as policy, investing environment and technology etc. should be fully considered. During the construction, investigation, consultation and argumentation should be carried out to set up reasonable risk response contingency plan in order to ensure an emergency response under any circumstances.



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