Promoting Stable and Consistent Renewable Energy Supply by Utilizing Suitable Energy Storage Systems

Study Report (Summary)

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(Summary)

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Chapter 1: Development Status of the Energy Storage Industry

In October 2012, "China's Energy Policy (2012)" white paper was released by China's State Council, stating that renewable energy will play an important role in China's energy development strategy in the next 5-10 years. Development targets for wind energy in 2015 and 2020 are 100 GW and 200 GW, and over 30 GW for solar PV in 2020. According to State Grid's "Opinion on Implementing Sound Distributed Solar PV Generation and Grid Integration Services" and other released policies, distributed renewable energy generation projects gradually increased. Energy storage is a supporting technology for achieving a grid with a high proportion of renewable energy. This development is inseparable from developing large-scale renewable energy and the grid integration of large scale renewables. Microgrids, rooftop building-integrated PV, and other distributed generation systems, will also provide opportunities in which energy storage can participate.

1) Status of energy storage technology development

Up to now, more than 10 energy storage technologies have taken shape globally. Megawatt-scale systems are trending from the dominance of a single technology to a more diversified field. Prior to 2009, sodium sulfur batteries made up 77% of the global installed capacity. Then, after 2000, other technologies gradually developed, with 42% of new installed capacity made up by lithium ion batteries, 18% by lead acid batteries, 2% by flow batteries, 8% by flywheels, and 29% by sodium sulfur batteries. In the last few years, energy storage projects have developed in more and more fields, including wind farms, island and other remote region microgrid systems, frequency regulation and ancillary services, transmission and distribution systems, and others.

2) Direction of energy storage technology development

Focal points of future energy storage technological development are strengthening technological R&D, breakthroughs in materials and processing techniques, and achieving scalable demonstration applications and even commercialized applications. It is predicted that the next 3-5 years will focus on R&D of all types of critical battery technology (including battery materials, battery management systems (BMS), etc); in the next 5 years, battery processing and production and reliability will trend towards maturation, the initial steps of demonstration application testing will become possible, as will the scaled demonstration and even commercialization of some battery technologies.

Chapter 2: Energy storage applications in the new energy field

There are two dimensions in the concept of advantageous use: the technological feasibility of the application, and its definite economic value. This chapter will discuss the feasibility of types of energy storage uses in the renewable energy field, and the methods used in studying the economic value of energy storage.

1) Status of energy storage applications in the new energy field

When energy storage is applied in new energy fields, it can be classified into either power applications or capacity applications. Power applications are operations where, via short-term rapid charging or output actions, problems brought by the intermittency and fluctuations of wind and solar power are resolved. These mainly include the smoothing of wind farm output, planned output tracking, maintaining microgrid power quality and improving local renewable energy penetration rates, and frequency regulation and ancillary services, etc. Capacity applications resolve issues where power generated by new energy does not completely match the load, which mainly includes peak shaving and load shifting.

Energy storage has not yet reached large scale commercialized use in any country. At present, the demonstration projects of many countries (including those touched upon in this report), are divided by type of energy storage application for testing and verification. Actual operating results of demonstration projects are shown. From a technology perspective, all energy storage can realize the above-mentioned applications, improving the utilization of new energy, and promoting the development and supply of new energy.

In addition to verifying technical feasibility, being economical is largest problem facing energy storage and new energy at present, in achieving large scale use in renewable energy, and promoting the stability prerequisites of new energy supply. This text takes as a basis the technological feasibility tests already in progress at demonstration projects, emphasizing the economical nature of energy storage in its analysis.

2) Selection of energy storage economic research methods

a) The significance of energy storage economics research

At the present stage of market development, energy storage technology is still very expensive, and how the value and application of energy storage can gain corresponding returns is extremely crucial. However, there are still great difficulties in the accurate comprehensive evaluation of the economics of energy storage. When the CPUC (California Public Utilities Commission) solicited the energy storage industry for recommendations on how to formulate California's energy storage procurement bill, many public utilities and battery manufacturers all replied that difficulties in measuring the value of energy storage were already the largest barrier to the development of the energy storage market. At this stage of the investigation into the economics of energy storage, researching methods or tools that can comprehensively and accurately measure the economical nature of energy storage are very important:

(1) Helping owners of energy storage plants clarify, based on present conditions, if energy storage can be profitable, and ranking the profitability of all applications (or scenarios);

(2) Helping electric companies clarify if energy storage can increase the overall system's utility rate, and what the optimal scale of energy storage is;

(3) Helping battery manufacturers clarify which products are most suited for which fields of application;

(4) Helping government branches view the use of energy storage from an overall social benefit perspective, as well as in setting appropriate price signals to ensure that energy storage receives the proper return.

b) Introduction to energy storage economics research methods

(1) Status of energy storage economics research within and outside of China

A few government organizations, research institutes, industrial associations, consulting firms, and public utilities, etc., have already begun a certain amount of work on studying the economics of energy storage. Both industry participants and outsiders have some rather clear recognition of methods for calculating the measures of energy storage economics and valuing energy storage. The results of the research on energy storage economics by some research institutions are shown below.

Table 1: Energy storage economics research results from inside and outside China

Research Institution	Research Method and Results
Navigant (US clean-tech market research firm)	Navigant will create SGCT (Smart Grid Computational Tool) based on the approach developed by the Smart Grid Cost-Benefit Analysis (CBA) team under the US Dept. of Energy's Office of Electricity Delivery and Energy Reliability. This evaluates the performance, benefits, and costs of all smart grid projects that puts these figures into ExcelTM tools. Towards expanding the uses and functionality of SGCT, the Energy Storage Computational Tool (ESCT) was developed for evaluating the costs and benefits of energy storage, and helps analyze projects already in operation.
EPRI (US Electric Power Research Institute)	In early 2013, EPRI promoted its Energy Storage Valuation Tool (ESVT) software package, which, via defining applications and scenarios, calculated real-time earnings for energy storage step by step, use net present value methods to find the break-even point, and finally investigate corresponding business models.

NREL (US National Renewable Energy Laboratory)	NREL considers energy storage devices that provide only peak shifting, only reserves, or both peak shifting and backup reserves. PLEXOS simulation software is used to compare the three by running simulations both with and without the energy storage device and comparing the difference in operating costs of the whole system (including operation and maintenance costs and fuel costs). Of these, under the peak shifting only condition, NREL noted that according to present calculation methods, the earnings of energy storage plants are less than the actual value they create for the electric system, and recommend a change to the present compensation system.
Frontiers energy in research (German research firm)	Frontiers in Energy Research pays an even closer attention to concrete application studies, putting forth its Levelized Cost of Electricity (LCOE) method. Using concrete use differences, energy storage's change and discharge frequencies will be somewhat different, thus leading the life cycle cost of energy storage to also have some differences. Frontiers did a sensitivity analysis on lifecycle costs, finding the different LCOE's under different application and usage conditions.
China Defense Scientific Research Institute	Put forth YCC index concept, the YCC index represents the cost of all electricity charged and discharged over the energy storage system's entire lifecycle.
Chinese Academy of Sciences Institute of Engineering Thermophysics	Professor Chen Haisheng of the Chinese Academy of Sciences Institute of Engineering Thermophysics studied the pay-back rates of different energy storage technologies under different electricity purchasing structures and retail prices from a tax policy perspective.

Source: Collected and arranged by CNESA

(2) Investigation of energy storage economic research methods

Based on the scope of all considered value of energy storage covered, current calculation methods can be generally categorized into three types:

(a)Methods where return on investment of energy storage is calculated using only the market opportunities provided by the existing compensation system. Indirect returns or indirect returns not supported by the market compensation system are not included in the calculation of profits.

(b)Methods where all earnings of energy storage in the electric system are considered (even though the beneficiary may not be the energy storage device), but does not consider the social benefits of energy storage (such as emissions reduction, increasing the operating efficiency of other units, and increasing infrastructure utilization rates, etc.)

(c)The entire local electric system is the object of study; via comparing the costs of operating the entire local electric system with and without energy storage, the value of the energy storage device is calculated. This method can reflect the true value of energy storage, and can help policy makers introduce compensation measures for the value the energy storage provider creates but cannot capture.

(3) Selection of these project research methods

Taken with the current stage of the energy storage industry's development, this report will only calculate the individual application value of energy storage. In addition, the calculation methods discussed herein only touch upon grid integration projects; off-grid projects will be explained separately.

Before the calculation of specific cases, this report will first define the use of energy storage in wind farm grid integration, and explain the corresponding earnings calculation method and formula that must satisfy technological requirements. Secondly, parameters of the case are determined, such as its location, the wind farm's installed capacity, the conditions of wind resources, energy storage capacity, charge and discharge times, the whole system's initial investment, local electric system regulatory rules, and the owner of the energy storage device, etc. Continuing to use the net present value approach, calculating yearly earnings and costs, and cost benefit ratio (benefit/cost), if the ratio is larger than 1, it means that under present market conditions, the energy storage might be profitable, and if it is less, then it likely won't be profitable. Finally, separating the plant's earnings, the battery's life cycle, and government policies for analysis, the whole project's uncertainty factors can be tested via sensitivity analysis.

Chapter 3: Advancing Wind Farm Development with the Use of Energy Storage

In 2012, the Northeast Power Grid used 1490 hours of wind power, significantly lower than in other regions. Under these conditions, the Beizhen Energy Storage Wind Farm project was designed in 2011, and commissioned in 2013.

The purpose of the Beizhen Energy Storage Wind Farm is to analyze the practical operating conditions of an energy storage system in a wind farm, test its various applications and functions, and via experimental data investigate and verify the optimal operating methods of the energy storage system. The project, as such, is an investigative demonstration project, and offers significant guidance for research on using energy storage to resolve problems with wind generation. The below table provides basic information on the Beizhen Energy Storage Wind Farm project.

Table 1: GuodianHefengBeizhen Energy Storage Wind Farm Project specifications summary

Wind farm size (MW)		99
Energy Storage	**Technology**	Lithium iron phosphate battery (5MW*2h) All-vanadium flow battery(2MW*2h)
	Rated power (MW)	7
	Discharge time (hours)	2
Feed-in rate (CNY)		0.61
Application (functionality)		Load shifting
		Planned output tracking
		Wind smoothing
		Frequency regulation

Source: Beijing HuadianTianren Electric Power Control Co., Ltd.

This section will analyze four applications: load shifting, planned output tracking, wind smoothing (smoothing wind energy output), and frequency regulation.

1) Economic analysis of load shifting

Load shifting is, when the grid dispatch requires the wind farm to limit its energy output, the wind farm charges the battery with the excess energy, and conversely, when there are no such limits, the battery feeds its energy onto the grid. Using energy storage for load shifting is a solution to wind curtailment issues.

China's wind farms use a fixed feed-in rate policy; if there is no energy storage, the price of electricity when wind power is being limited is given no consideration. After installing an energy storage system, each time a set amount of wind energy is used to charge the battery, the portion of the energy remaining after losses due to battery inefficiency, according to the national set feed-in rates for grid companies selling electricity, the corresponding calculation formula is given by (1):

$$\mathrm{B} = \mathrm{P} \times \mathrm{f} \times \sum_{0}^{n} E \qquad (1)$$

B is yearly earnings (CNY/year), P is the local price of wind power (China uses a fixed feed-in rate for wind power, and this project's feed-in rate is 0.61 CNY/kWh), f is the efficiency of the energy storage system (%), and E is the one-time charge-discharge capacity (kWh).

Table 2: HefengBeizhen region wind farms curtailment data

Month	05/2012	06/2012	07/2012	08/2012	09/2012	10/2012
Generation capacity MWh	8560	8210	5180	4820	6840	7950
Curtailed wind power MWh	680	340	300	410	540	1769.4
Curtailment rate	9%	5%	7%	8%	7%	18.89%
Month	**11/2012**	**12/2012**	**01/2013**	**02/2013**	**03/2013**	**04/2013**
Generation capacity MWh	6050	7100	4850	4510	8180	10040
Curtailed wind power MWh	2152.4	1970	1770	5200	4170	340
Curtailment rate	24.87%	20%	28%	40%	35%	3%

Source:China GuodianLongyuan Power Group Corporation Limited

From the above table, we can see that curtailed wind occurs mainly in the winter months when home heating is being provided (from October to March - in China, central heating in buildings is controlled by the government and turned on and off at a set time each year). Supposing that curtailment occurs each day, then it occurs about 182.5 days out of the year (365/2=182.5). In addition, this curtailment occurs mainly at night, so an energy storage system could be charged in this period, and sell energy to the grid the next day during wind curtailment periods. The curtailment rate during the non-heating period is relatively less and more dispersed; under each condition, the installation of energy storage could be able to capture all curtailed wind.

Based on the above assumptions and the data in table 3, according to formula (1), HefengBeizhen wind farm energy storage system's load shifting application could bring in 1371 RMB of revenue this year.

2) Economic analysis of planned output tracking

Tracking planned output refers to when short-term wind power forecasts results and dispatch order timely revisions to the previous day's forecast curves, reducing forecast error and simultaneously satisfying the requirements of dispatch.

China's NEA (National Energy Administration) issued its "Provisional methods for wind farm power forecast management" in September 2011 which addresses wind farm forecast accuracy and yield, the sets detailed grading evaluation systems, examine exceptionally good wind farm priority dispatch, and then receive greater feed-in quantities.

Energy storage applications in planned output tracking and the corresponding earnings can calculatedby comparing the change in wind power forecast accuracy, dispatch ranking, and final electricity sales before and after the installation of energy storage at a wind farm. The calculation method is shown in formula (2):

$$B=P \times C \times (T1 - T0) \quad (2)$$

where B is yearly earnings (CNY/year), P is the local price of wind power (0.61CNY/kWh), C is the wind farm's installed capacity (99MW in this case), T1 is the yearly usage hours of the wind farm after the energy storage system has been installed, and T0 is the usage hours of the wind farm before the energy storage system was installed.

At present China has yet to carry out this aspect of the actual experiment, the related data is lacking, and a quantified calculation will not be done here.

3) Economic analysis of wind output smoothing

Wind farm output will, because of wind gusts or rapid drops in air pressure gradients, and other changes in weather factors have severe production fluctuations. Larger short term fluctuations will increase the electric system's difficulty in peak shifting and frequency regulation. Smoothing wind output refers to the frequent charging and discharging of the energy storage system to make the wind output smoother, and make the ramping rates and ramping ranges satisfy the grid's dispatch requirements.

The energy storage system has a rather fast response speed, and can be integrated with wind forecasting technology, ramping forecasting, and prepare energy storage charge and discharge plans in advance. It can thus smooth the wind output, reduce the impact of wind ramping on the system, and as such reduce the installed capacity of the electric system's reserve capacity, increasing the utility rates of the electric system.

At present, how to forecast ramping, quantify wind output smoothing, and quantify their impact on the operation of the electric system, are still in the research phase. Demonstration projects for energy storage in wind farms at present are also in the functional implementation phase for this application. As the corresponding incentive mechanisms, testing mechanisms, and price setting methods have yet to be launched or put into effect, these partial revenue streams at present cannot be quantified. However, if wind farms installed energy storage equipment, it could thus lead to the storage of curtailed wind, reducing the corresponding losses.

4) Economic analysis of frequency regulation

Energy storage in frequency regulation is when, within an energy storage system's rated power and set capacity, according to automated generation control signals (AGC), provides frequent charge and output functions on the grid, maintaining the system's frequency within its specified range.

According to the related provisions in the "Trial practical rules and regulations for the management of grid-connected power plant ancillary services in the northeast region," AGC allocates and at a compensation rate of 600 CNY/10000 kWh (60 CNY/MWh), adjusts capacity and increases or decreases generation capacity within a set absolute value; where increasing and decreasing generation both receive the same compensation.

As at present energy storage cannot independently integrate with ancillary services, we hypothesize that the participation of energy storage with AGC services would have gains similar to those according to the above compensation standards of thermal (traditional) power plants and hydro plants. Energy storage responds much faster, does not have delays, and will not give rise to punitive costs and fines.

On the basis enumerated above, energy storage the annual revenue stream can be calculated by formula (3):

$$\mathrm{B} = \mathrm{P} \times \sum_{0}^{365} \sum_{0}^{96} \int_{0}^{\frac{1}{4}h} (|\Delta P(t)| - k(|\Delta P(t)| - 7000)) d_t$$

$$\text{if } |\Delta P| \geq 7000, k = 1$$

$$\text{if } |\Delta P| < 7000, k = 0 \quad (3)$$

where $\Delta \mathrm{P}(\mathrm{t}) = P_2(t) - P_1(t)$, the difference between planned output, P1(t) (kW/h), and that ordered by AGC, P2(t) (kW/h)

As both generation increases and reductions receive compensation, the absolute value of ΔP is used in the calculation of compensation.

Current systems will divide the day into 96 time periods for control (each period being 15 minutes), so this is the time frame used in the calculation. The each yearly period is added into the yearly increased and decreased generation total, which gives the total frequency regulation capacity provided for the year.

P is the frequency regulation price, which is 0.06 CNY/kWh (or 600 CNY/10000 kWh) in this calculation.

Chapter 4: Advancing the development of distributed generation and micro grids via the application of energy storage systems

Along with the development of new types of generation technology including wind, solar PV and other renewables, and high-efficiency clean coal, distributed generation (DG) is gradually meeting more load requirements, decreasing pollution, increasing energy integration utility rates, and is becoming an effective channel for power supply reliability.

However, the large-scale penetration of DG also creates some drawbacks, such as the high costs of distributed generation unit integration, and more complex controls. To consolidate the advantages of DG, mitigate its drawbacks, and provide ample displays of the value and benefits of DG, related electricity workers and experts put forth the micro grid concept.

Micro grid refers to an autonomous system capable of self-control and self-management and is comprised of distributed power resources, transformers, load, supervision, and safety devices and other small-scale generation and distribution system components. Micro grids can be regarded as small-scale power systems, possessing complete generation and distribution functionality, and are capable of effectively realizing energy optimization within its own grid. Micro grids sometimes, while meeting user electricity demand, also have to meet heating demand. As such, these current micro grids are in reality energy networks. Depending on whether it is connected to the main grid or not, micro grids can be divided into grid-connected micro grids and independent micro grids.

This section will compare the Guodian New Energy Technology Research Institute's Wind-Solar-Storage combined generator experimental project and the Bange Highway Maintenance micro grid project, and discuss the application, economics, and calculation methods of energy storage in grid-connected micro grids and independent micro grids.

1) Grid-connected micro grid case study

a) Overview: grid connected micro grid case study

The Guodian New Energy Technology Research Institute's wind-solar storage hybrid system study is comprised of 2.58 MWp of rooftop solar PV power, 1.5 MW wind power, and a 500kW/100kWh energy storage system.

It has a capacity of 130kW of solar PV power by way of a 20kW solar inverter step-up unit with 380V post-inverter voltage system. Capacity of the 2.43MWp solar PV system, 1.5MW wind power, and 500kW/1000kWh energy storage system are each stepped up to 10kV and fed into a 10kV generating line (bus), and finally out of the return line connected to the #1 10kV distribution installation at the #1 Research Building, where it is connected to the grid, and satisfies the wind-solar storage system's independent operation experiment requirements.

The Guodian New Energy Technology Research Institute's wind-solar storage system study distribution and structure schema is shown in the below figure.

Figure 1:Guodian New Energy Technology Research Institute's wind-solar storage system study distribution schema

Source: Guodian New Energy Technology Research Institute

b)Economic analysis of a grid-connected micro grid case

The Guodian New Energy Technology Research Institute wind-solar storage hybrid system study is a grid connected micro grid (MG Connected Regional Grid). When the main grid is operating regularly, micro grid and major grid integrate operations. When testing faults in connecting with the greater grid or when power quality does not meet requirements, the micro grid is disconnected, and begins independent operations. When operating independently, the distributed power sources within the micro grid ensure uninterrupted power supply to important loads, and maintain supply-demand balance within itself.

The wind-solar storage system has three major economic benefits: electricity price arbitrage, increasing the local renewable energy penetration rate, and independent operation.

Electricity price arbitrage

Each country's electricity market hopes to influence the usage of electricity via price signals, reducing the peak load via high prices during peak usage hours and low prices during low usage hours. When the price is lower, the battery charges, and when the price is higher, the battery provides power to the local load or grid, and will give the owner/operator of the energy storage system a set benefit or reduction in electricity fees.

Revenues from user-side energy storage in electricity price arbitrage include peak off-peak price difference arbitrage, and reducing basic capacity costs. According to the stipulations of the Beijing NDRC (National Development and Reform Commission), the Guodian New Energy Technology Research Institute building uses 1-10kV, with an electricity price that does not include a basic capacity price, with the price being defined as shown in the table below.

Table 3: Beijing grid peak and off-peak consumer electricity rate table (CNY/kWh)

	Peak	Average	Off-peak
Summer	1.195	0.819	0.342
Non-summer	1.195	0.784	0.395

Source: China Electric Information Publishing Network

Assuming that the energy storage system charges and discharges each day of the year, charging during off-peak hours and providing energy to the grid during peak hours, B in formula (4) shows how much revenue the device would generate:

$$B = (P_{ps}f - P_{vs})CT_s + (P_{po}f - P_{vo})CT_0 \quad (4)$$

where P is the user electricity price (P_{ps} and P_{po} are summer and off-summer peak prices, $P_{\mathrm{vs}}$and P_{vo} are summer and non-summer off-peak prices); f is the cycle efficiency of the energy storage system, which is 80% in this case; C is the energy storage system's capacity, 1000 kWh in this case; T_S is the number of summer days in the year, 62 in this case; and To is the number of non-summer days, 303 in this case.

The results show that the Guodian New Energy Technology Research Institute wind-solar storage hybrid system study can save 208,051 CNY per year via electricity price arbitrage.[1]

Increasing the local penetration rate of renewables

Increasing the local penetration rate of renewables via energy storage is mainly to avoid grid renewable generation feed-in limitation issues. According to the load and wind output relationship, via controlling the battery's charging and output, can to the utmost ensure the local consumption of wind energy, and ultimately realize the goal of using a high proportion of energy from renewables.

As in China, the costs of wind and solar power are currently still greater than local retail electricityprices, the majority of localities that already have a large proportion of renewables consumption cannot receive economic benefits from them. Thus, purely from a standpoint of increasing local renewables consumption, one cannot evaluate the value of the wind-solar storage hybrid system study's earnings very well. This project is more to investigate the possible problems and difficulties of having a high-proportion of renewables on a local system.

[1] Summer prices are used from July 1 to August 31, a total of 62 days; the rest are non-summer.

At present, in Germany, Japan, Australia, and other countries with high electricity prices, large peak and off-peak price spreads, and subsidies for energy storage, energy storage use in distributed generation and micro grid systems for raising the local renewables penetration has already seen a certain amount of development. As China's costs of new energy generation decrease and those of petrochemical generation increase, when the costs of integrated wind, solar PV, and energy storage generator plants are less than grid retail prices and can meet user return on investment requirements, then this application can reach wider use.

Independent operation

A primarily wind and solar PV generation-fed micro grid that is outfitted with sufficient energy storage batteries can rapidly switch over to independent operation modeduring a grid generation failure. This thus ensures the in-advance provision of electricity to important loads, and increases the reliability of the energy used by this portion of the load.

In the Guodian New Energy Technology Research Institute's wind-solar storage hybrid system study, during micro grid independent operation, the major function is providing electricity to underground lighting, including evacuation and emergency lighting, the economic value of which is very difficult to determine. Thus, we mainly applied the power outage damages compensation method to quantify the value of the increased local reliability provided by the micro grid.

According to stipulations in the 1996-issued "Rules and regulations for electricity providers," power outage damage compensation is determined by formula (5):

$$\mathrm{B} = 4 \times \mathrm{P} \times \mathrm{C} \times \mathrm{T} \quad (5)$$

whereB is power outage damage compensation, P is the average price of electricity, C is the average amount of energy that would have been used during the outage, and T is the duration of the outage. The total compensation is calculated with four times the electric usage rate.

As the data shows, in Beijing in 2013 the city grid in one season had a reliability rate of 99.9978%. With this as a baseline, Beijing has 0.1927 hours of power outage each year (24*365*(1-99.9978%)). With the yearly total not even exceeding one hour, it is reasonable to assume that this will generally be the case. "Rules and regulations for electricity providers" dictates that when power is out for less than one hour, one hour should be used in the compensation calculation. Thus, if the total number of outages per year is*n*, total power outage damage compensation can be estimated as *n* hours. In addition, when calculating the compensation, each time the power goes out, the capacity used is the rated power of the energy storage times one hour, or 500kWh in this case.

Considering the price structure at the Institute, based on formula (5), it is likely that in a whole year*n* power outages will occur during the lowest price period (non-summer off-peak, when electricity prices are 0.342 CNY/kWh). Thus, the value of energy storage in power outage damage is 684*n CNY (4*0.342*500*n); for the upper bound case, assuming all outages take place during peak hours, the value would be 2390*n CNY (4*1.195*500*n).

As power outages often occur at unpredictable times (random distribution), thus, the practical economic value of the independent operation functionality of energy storage is between these two bounds, 684*n≤B≤2390*n.

From the above calculation it can be seen that the outage compensation rate calculation for micro grid reliability benefits is rather small. This shows that on one hand, the current compensation mechanism could be improved; and on the other hand, based solely on this compensation mode's value of the strengthened load reliability of a micro grid cannot reflect the value of energy storage and micro grids, especially when considering the total societal benefits, such as in disaster and war scenarios.

2) Independent micro grid case study

a) Overview: independent micro grid case study

China's government attaches great importance to the un-electrified region and rural population problem. In the "12th Five Year Plan: Energy development," measures for such efforts are laid out, including the following two methods: building new grids and expanding grid coverage, and the construction of independent micro grids.

Independent micro grids, without connection to the main grid, via the use of renewable energy sources, build micro-hydro, small-scale wind, and home solar PV systems, where wind and solar provide mutually complementary power with other small scale power units, forming a diverse supply of power, and addressing the un-electrified region issue.

The Bange Highway Maintenance independent micro grid project, established in 2011, is still not connected to Bange County's main grid. With barely any construction as of 1999, a 70 kW solar PV plant, as well as a 2*20 kW diesel generator make up the independent micro grid system. However, this system and Bange highway maintenance crew's work extends far beyond the local low voltage transmission distance, and is even out of range of the existing Bange independent micro grid.

In addition, the Bange Highway maintenance crew's electric load is entirely classified as meeting basic residential subsistence household load. It has no local transformer or dispatch infrastructure whatsoever. As such, it seems that if the grid extension method were selected, it would require the construction of a new transmission line with distribution and transformer equipment, a very large initial investment, with a very low utility rate for the equipment. As such, the Bange highway maintenance crew ultimately opted to build a new independent micro grid to meet their electricity requirements.

The Bange Highway maintenance crew micro grid system uses wind and solar power technology to resolve its un-electrified region power supply problem, does demonstration work, and is a welfare project of the national 12th FYP (Five Year Plan) on resolving the electrification issue. Via the project's demonstration aspects, this type of grid could be used in China's populated islands, remote rural areas, and other locations.

The key performance parameters of each part of the Bange project are shown in the table below.

Table 4：Bange Highway independent micro grid project: key performance parameters

Component	Wind power (kW)	Solar cell power(kW)	Energy storage battery capacity (kWh)	DC control system	Inverter	AC dispatch system	Backup diesel generator
Parameter	35	25kWp	540KWh	5kW, DC360V, 12 route control	200kVA, AC380V50 HZ	AC380V Three-phase four wire	None

Source: Beijing HuadianTianren Electric Power Control Technology Co., Ltd.

b) Economic analysis of independent micro grids

Generation capacity calculation

The system uses a 35 kW wind power system and a 25 kWp solar PV system for complementary generation for a living and simple manufacturing load. The wind system and the solar PV system produce electricity, separated by a wind turbine control device and a solar PV control device connected to charging the energy storage battery. An inverter follows the battery energy storage source and provides AC for the load. Under strong wind and abundant sunlight conditions, the battery can be basically kept in a charged or overcharged state.

Based on the local sunlight and wind resource availability calculations, the solar PV system's annual generation capacity is about 45625 kWh, and the annual wind generation capacity is 63000 kWh. Taking the energy losses due to the inverter’s inefficiency into account, a DC to AC conversion rate of 0.8, the whole system can provide 86900 kWh/year. Field measurements and usage statistics found the annual production capacity to be 82729.44 kWh.

Generation cost analysis

In micro grids with wind and solar and other intermittent sources as their main power source, energy storage batteries serve to ensure the frequency and voltage stability of the system, and are an essential component of the independent micro grid. Other types of batteries may be chosen, but other technologies cannot be substituted.

Where energy storage costs are higher, different configurations of energy storage directly influence the economics of the whole independent micro grid. As such, how to allocate the amount of energy storage depends on satisfying the constraints (such as reliability requirements, initial investment, emissions standards, etc.), and is also related to the type of controls. Thus, energy storage in the economics of independent micro grids must be considered from the view of the whole micro grid; satisfying the above restricting conditions and minimizing generation costs.

The BangeHighway independent micro grid project costs are mainly made up of facility and installation engineering estimates, construction engineering estimates, survey design estimates, and other costs. Of these, the project equipment and installation engineering estimates totaled 2.62M CNY; wind turbines, solar PV, and distribution facilities and other major equipment were considered to have a lifetime of 20 years. The batteries of this project were classified as fixed use, and, taking the battery's useful lifetime, technology upgrades, and price change factors into consideration, the system's maintenance cost is 450,000 CNY. In the 20 year life cycle, the total cost of all equipment is 3.07M CNY, and the micro grid's annual generation capacity (accounting for efficiency losses due to the batteries) is 8279.44 kWh. The micro grid's price per kWh is 307*10000/(82729.44*20) = 1.85 CNY/kWh. The local cost of diesel generation in Tibet is around 2.65 CNY, which does not even take into account the greenhouse gas emissions and other environmental aspects. Using a micro grid with wind, solar, and energy storage the generate energy costs less than using diesel generation.

Chapter 5: Impact of the national government on the practical economics of energy storage

The energy storage industry is still in the early industrialization stage. Technological developments and improvements are still without question just beginning the demonstration project and function/application experimentation phases, and focused government assistance is urgently needed. Government support and subsidies can help enterprises reduce some of their costs, form mainstream technology and applications, and to a certain extent lead the direction of industrial development.

1) Status of China's energy storage policy support

Policies related to energy storage can be categorized as either direct policies or indirect policies. Direct policies are mainly energy storage industry development planning, energy storage pricing policies, the proportion of energy storage in the electric system, etc. Indirect policies do not necessarily mention energy storage, but their implementation can create more advantageous development environments for the energy storage industry.

a) Status of China's explicit energy storage supporting policies

In the policies currently issued by China, there are three types that explicitly implement and increase support of the energy storage industry's development. These include energy storage demonstration project construction programs, energy storage technology and equipment research programs, and propulsion energy storage battery development programs. Examples include:

"12th Five Year Plan: Renewable energy development"

"12th Five Year Plan: National energy technology (2011-2015)"

"Technology Development 12th Special Five Year Plan: Solar generation"

"Technology Development 12th Special Five Year Plan: Wind generation"

"Major Technology Industrialization 12th Special Five Year Plan: Smart grid"

"Industrial Development Plan (2012-2020): Energy efficient and new energy vehicles"

and others.

These policies have already begun to actively support energy storage technology R&D and encourage energy storage technology diversification and scaling, including physical energy storage technology, chemical energy storage battery technology. All contain action related to energy storage R&D or the R&D of critical related materials and components, and all receive whole-hearted policy support. In addition, it is through the beginning of demonstration project testing and the development of energy storage technology, the functional verification of energy storage applications, and the quickening of the process of energy storage technology development, that these policies take shape to a certain degree.

b) China's indirect energy storage supporting policies

China has also issued a number of policies that indirectly support the energy storage industry's development. These are mainly new energy generation consumption and grid feed-in policies, pilot peak and off-peak electricity pricing policies, and policies that encourage industrial development. Examples include:

"Guiding opinion on the early-stage construction of distributed access wind generation projects"

"Distributed generation management methods (Request for opinions manuscript)"

"Renewable energy electric quota management methods (3rd forum)"

"Provisional measures for central financial incentive fund management of urban comprehensive pilot demand-side electricity management efforts"

"12th Five Year Plan: National strategic emerging industry development plan"

In the above policies, the consumption of renewable energy generation problem is a major focus, with centralized and distributed renewable energy both receiving policy support and incentives. Energy storage technology will play a major role in renewable energy generation, especially in distributed renewable generation. Demonstration projects can receive national financial support, thus strengthening the enthusiasm of all parties involved in the development of such demonstration projects.

Using energy storage technology to promote renewable generation, at present, is still facing many challenges. First, energy storage technology needs to improve in efficiency, reliability, lifecycle length, and others factors. Next, energy storage equipment costs are very high; reducing these costs involves raw materials, integration, scalable manufacturing, and many other aspects. Finally, energy storage applications still require much more demonstration project testing; this is also a key factor in technology improvements and cost reduction.

Although China already put into effect many policies that support the development of energy storage, regardless of whether direct or indirect, the strength of subsidy quotas for energy storage R&D and demonstration projects are not clearly defined. There is a critical lack of price mechanisms and market rules and regulations that can reflect the advantages and benefits of energy storage. The energy storage industry urgently needs the implementation of stronger, more focused policy to help energy storage better participate in the market, achieve economic practicality, and then as such advance renewable energy development.

2) Impact of new energy storage policy on the practical application of energy storage

China's energy storage industry has just begun to progress. In the future, it is important that formulation of China's energy storage policy addresses these four aspects: short term and medium to long term energy storage planning; electricity pricing policy; incentive policies and subsidies promoting energy storage application; and complete policies regarding the advancing of energy storage technology and related standards.

Energy storage short term and medium to long term planning Short term planning is mainly specifying 2-3 important development technology paths, establishing financial support for demonstration projects, and major application directions. Medium to long term planning emphasizes R&D in emerging technologies, increasing the domestic production ratio of energy storage technology, and deep research and promotion of scaled production for addressing target cost issues.

Electricity price policy Electricity price policy is divided into direct pricing policy and indirect pricing policy. Rational peak and off-peak pricing, industrial user capacity pricing, and other indirect pricing policies were launched first, thereby stimulating the development of energy storage. As the impact of these indirect pricing policies gradually weakens, direct pricing policies are gradually implemented. Direct electricity pricing policies mainly include subsidized electricity prices for wind farms and solar PV plants outfitted with energy storage systems, subsidized electricity pricing policies for distributed micro grids with energy storage, electric prices for generation-side ancillary service energy storage, etc. Direct electricity pricing policy will establish a mechanistic basis for the real commercialization of energy storage.

Incentive policy and subsidies for energy storage demonstration applications This type of policy mainly includes the direct financial support of major demonstration projects, the introduction of financial support to demonstration projects, energy storage equipment investment subsidies, energy storage equipment installation, and funding research for soft energy storage issues. The implementation of supporting demonstration project policy can help energy storage verify technology, clarify application types and economic value, and ultimately achieve profitability. Energy storage soft issue studies can bring about the advantages in an energy storage alliance platform and industrial research, and facilitate communication and coordinate cooperation among energy storage technology vendors, electric institutions, research institutes, and other groups to provide a basis for advancing the setting of policy.

Incentive policies for energy storage technology research and standardization In accordance with short term and medium to long term planning, Incentive policies for energy storage technology research and standardization involves choosing several types of mainstream developing technology, and setting the corresponding energy storage technology R&D and standardization incentive policies. This type of incentive policy also includes pre-mainstream technology and application system R&D incentive policy, emerging (future emerging) technology R&D support subsidies, technology standardization policy (international), etc. For mainstream and emerging technologies, setting technology R&D incentive policies, and subsidy incentive policies can systematize the management of R&D funds, improve their use in any stage, and make up for a deficiency in funding for emerging and early stage technology R&D. The setting of standardization is the basis of technology development, setting its direction, and advantageous successive industrial development. In addition, it can also establish a corresponding energy storage primer fund, combining the specializations of government funding and venture capital institutions to help energy storage technology develop towards industrialization.

Other indirect energy storage industry supporting policies The energy storage industry's development and national energy policy, electric system development direction and other closely related things; the promotion policy of these fields all will indirectly advance the energy storage industry's development. These include: renewable energy feed-in percentage rules, distributed micro grid development policy, electric system marketization policy, and others.

Chapter 6: The active role of rational application of energy systems in industry

Energy storage can increase the quality of wind and solar power, helping the grid to better accept these intermittent energy sources, and is gradually gaining a wider recognition. However, at the present stage of industry development, the concrete applications of energy storage still require further verification. The corresponding economic metrics of these applications also have certain difficulties; policy structure, etc., also has a rather large disparity. How to better use energy storage systems and promote renewable energy development is an issue of universal concern within the industry.

Guodian Group is the generation group with the largest proportion of renewable energy installations in China. Its vigorous advancements include wind farm energy storage, distributed generation micro grid energy storage, and other types of experiments, breaking ground on demonstration projects, verifying technological feasibility, and searching for generalizable models, etc. This report analyzes three Guodian Group projects that have already been launched, ties in the relevant policies and legislation, and investigates the value of energy storage applications in renewable generation and the role it plays in its development.

1) Energy storage application in wind farms

Combining the HefengBeizhen energy storage wind farm project, this report will analyze the four major types of energy storage applications, their individual economics and rationality under the present conditions.

a) Peak shifting

Resolving wind curtailment issues is a real critical problem facing a portfolio with a high proportion of wind energy. Due to the geographic disparity between China's wind resources and its load, plus considering the cost of transmission line construction as well as the losses in efficiency deriving from such long-distance transmission, energy storage peak shifting will be a core method to resolving wind curtailment. Although energy storage peak shifting at the present stage is not economical, and cannot achieve profitability, from a medium to long term perspective, as energy storage technology matures and its scale of application expands, the system costs will go down. Furthermore, with the addition of each national policy and subsidy support, the use of peak shifting energy storage capacity will gradually increase, becoming more profitable in the future.

b) Planned output tracking

Planned output tracking functions are currently a necessary capability for wind farms to possess. Increasing the accuracy of forecasts, advantageously setting the grid company's generation plan, and easing grid frequency pressure, decreasing the system's reserve capacity, and increasing the grid's ability to accept wind power feed-in. Energy storage is one effective means for improving forecast accuracy, but as at present review mechanisms have not been put into practice, profit cannot be achieved. However, as related dispatch mechanisms continue to improve and are actually implemented, this can become a profitable method.

c) Wind output smoothing

Wind output smoothing can alleviate the impact of large short-term wind fluctuations on the grid, reduce the need for grid reserve capacity allocations, and increase the system's utility rate. However, one aspect of energy storage use in wind output smoothing still needs to be brought about at the present stage. Related incentive mechanisms and price setting methods have not yet been officially launched, so the economic benefits as such cannot be quantified. On the other hand, as wind energy technology progresses and the scale of wind farms expands, the fluctuations and differences between turbines will mutually offset, so wind output ramping will gradually decrease. Energy storage use in wind farms is an application that can be passed over and ignored.

d) Frequency regulation

Frequency regulation is an essential service in an electric system, provided by traditional generation resources (thermal and hydro plants) at present. Each region's grid already has a corresponding compensation method for it, but the present methods (ex. Northeast grid has capacity-based frequency regulation compensation) still cannot reflect the real value provided by energy storage. Furthermore, as the Northeast grid wind farm does not need to provide frequency regulation services, in the short term wind farm energy storage systems cannot even profit from frequency regulation applications. However, as wind farms enter the ancillary services market, if wind farms want to profit from frequency regulation services, it will be necessary to install energy storage systems (ex. Huabei grid will at present channel wind energy into ancillary services, however wind power has no means of providing frequency regulation, which is basically in the assessment stage). Furthermore, as frequency regulation compensation mechanisms are perfected, energy storage can perhaps be profitable in this area. This energy storage application is worthy of attention and expansion.

2) Rationality of energy storage applications in grid connected micro grids

Tying together the Guodian New Energy Technology Research Institute wind-solar storage hybrid generation pilot project, this report's analysis on the three types of energy storage applications, their economics and rationality under the present conditions, all have differences.

a) Electricity price arbitrage

Electricity price arbitrage is an application that a micro grid energy storage system can directly receive revenue from. Regarding large industrial users, energy storage, in addition to reducing high peak rates, can also reduce capacity fees by a substantial margin (in this case, electric users only involve peak prices, and don't necessarily pay capacity fees). The value of this energy storage application will increase even more. In China, peak usage rates are at present going up each year, with the spread between peak and off-peak rates widening. This price difference will inevitably cover more users, and with the widening price disparity, energy storage will become more profitable. In addition, when renewable generation in the micro grid is plentiful, it can be fed into the grid to generate extra income, and energy storage will get relatively good modes of profit.

b) Increasing the local penetration rate of renewables

China's current wind and solar generation costs are still high compared to local retail rates, so energy storage use in increasing the local penetration rate of renewables is not yet economical. However, this application does have future significance. As wind and solar energy costs and the costs of energy storage decrease to below that of the grid retail electricity prices, this application can be expanded in China when it can also satisfy customer requirements for return on investment rates.

c) Independent operation

Energy storage can effectively increase the reliability of important loads within a micro grid, however, with current power outage compensation rate calculations as they are, the amount of profitability energy storage can receive for this is very low, and not economical. However, with an increase in micro grids, the corresponding outage compensation methods will be improved, and this value of energy storage could be realized. Independent operation is an energy storage application that should be considered.

3) Rationality of energy storage use in independent micro grid projects

This section integrates the Bange highway maintenance crew project, this report's analysis of the reason for the use of this independent micro grid, and the analysis of the economics of each energy storage application in the project.

As this type of project is for the most part located in a remote area far from the main grid, such as islands and frontier rural areas, using local renewable energy generation to resolve the un-electrified population problems in these areas has obvious economic benefits from both grid and diesel generation perspectives. However, the stability of renewable energy limits it in this field of application. The involvement of energy storage is at the core of popularizing and expanding renewable energy independent micro grids, and is advantageous to the development of renewable energy.

At the present stage, renewable energy development can be advanced by energy storage in wind farms for peak shifting, planned output tracking, and frequency regulation applications, by energy storage in grid-connected micro grids doing peak shifting, and increasing the local renewables penetration rate, and by applications in independent micro grids. Although under present management mechanisms and pricing systems the value of energy storage cannot be reflected very well, as the related mechanisms improve, the gains brought by energy storage will gradually take shape, and the role it plays in advancing renewable energy development will become increasingly apparent.