Three Gorges Dam and the electric power systems in China

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Abstract

In this thesis, we have mainly illustrated the hydropower engineering and power transmission technology in China. Through the comparison between the greatest hydro power station, the Three Gorges Dam, with some other great stations, we have obtained the hydro power technology is now quite mature and efficient in practice with 90% conversion rate. Afterwards, we have explained the procedures of how the kinetic energy and/or gravitational potential energy are transformed to electric power. And meanwhile, this thesis gave the detailed introductions with plenty diagrams to elaborate the working status of Three Gorges Dam and also the working theory of turbine. At last, this thesis showed the distributions of the constructed grids, and indicated the main high voltage AC and DC transmission lines which connect different grids in mainland of China. This huge project has covered over 1 billion people. Besides, we have given some suggestions for decreasing the damage from the earthquake and freezing to grids. And this thesis is ended with our analysis and conclusions for what we have studied above.
Contents

1. Introduction ........................................................................................................ 1

2. History of the water power station ................................................................. 2
   First hydro electrical power in the world

3. Introduction of two important hydro electrical power stations ............. 2
   Three Gorges Dam over Yangtze River
   Compare the largest and second largest hydro power station
   ‘Niagara’ hydropower station in USA

4. General Knowledge of Three Gorges Dam .................................................. 4
   Advantages
   Disadvantages
   Environment influences
   Main Functions

5. The economical exploitation value and the developing level between
   China and the other countries over the world ........................................... 6

6. Generation Principles ....................................................................................... 9
   Theory of hydro electrical power station
   The working theory of the generators
   Formula and parameters for turbines

7. Comparison of the capacity difference between a variety of
   generation methods The Statements of Present Grids ............................. 14
   Comparison of the capacity difference between a variety of generation methods
   Electricity power generating proportion
   The power grid construction
   Power transmission

8. Before Three Gorges Dam had been constructed, how did China
   grid regulate the grid frequency ................................................................. 15

9. Adjustment of Grids ......................................................................................... 16
   How does the power station keep the same frequency with the grid
   How does the power station adjust when the frequency of the grid changes
10. Comparison the technique between HVDC technology and AC transmission

Flexible AC Transmission Systems
High voltage DC
Advantage of HVDC
Disadvantages of HVDC

11. The economy comparison between HVDC and AC transmission...

HVDC has lower investment in overhead line
Less investments in DC cable lines
The investment for converter station is greater than the substation
Less operating costs

12. Distribution of the grids in China

13. Earthquake and Freezing troubles for grids

14. Blackouts and their impacts

15. Analysis

The status quo of Three Gorges Dam
Efficiency and environment thinking of hydropower
The significance of constructing national grid

16. Conclusions

17. References
Introduction

In this thesis, we have studied and analyzed the techniques of hydropower engineering and the power transmission system. It is the Three Gorges Dam that has the largest installed capacity (22.4GW) and annual generation capacity (98.8TWh). Through the comparison between the Three Gorges Dam and some other types of stations, we obtain that the hydropower technique is quite mature and works efficiently in practice now. Nowadays the hydropower conversion rate, which means the efficiency of the power transformation from kinetic and/or gravitational energy to electric power, has already reached up to 90%, while the thermal conversion rate is less than 60%, due to the heat sinking in power transformation. And the Three Gorges Dam was the most typical case in high efficiency power station.

Afterwards, we have explained the theories about how the kinetic energy and/or gravitational potential energy are transformed to electric power. In hydropower system, the running water drives the turbines, and then, the generators on turbines start to work. Mechanical friction is the only cause of energy loss in the turbines.

Hereafter, this thesis shows the distribution of the grids and some high voltage transmission projects, which are transmission lines plus substations, constructed in mainland of China. There are six separate grids in China, and these projects serve like bridges between grids and make them work as one. This huge electric net has covered over 1 billion people and has supplied 4190 TWh electric energy per year. This thesis gives detailed introductions with plenty diagrams to the working situation of Three Gorges Dam. For instance, we have compared the two largest hydroelectric power stations: Three Gorges Dam and Itaipu Dam. The Three Gorges Dam has 32 units while Itaipu has only 20. However, their annual generation capacities are almost the same. The reason is that the Three Gorges Dam not only generates electric power, but also controls the flow quantity. However, Itaipu just concentrates on power generation. What is more, the annual runoff of La Plata Parana River (where Itaipu located) is larger than Three Gorges of Yangtze River (where Three Gorges Dam located). Then the thesis illustrates how the generators in the dam work, and the theory for the power conversion as well.

At last, we drew a map of Chinese grids distribution and another of the high voltage transmission lines deployed in China. China is the first country to run the ultra high voltage transmission system, and up till now, seven AC lines with one DC line which run over 1000kV have been deployed. They are effective in minimizing power losses in long distance transmission between different grids.

We have investigated the distributions of high voltage AC lines and DC lines. The AC lines are mostly drawn between two cities, acting as the substation hubs, while the DC lines are usually drawn between electric power bases and the grids with high power demand.
History of the water power station

• *First hydro electrical power in the world*

1878, France built the world's first hydropower station.

After the 1930s, the development on quantities and capacities in hydropower were great. In the late 1980s, most industrialized countries, such as Switzerland and France had started to develop hydro power.

In 20th century, the world's largest hydropower station, Itaipu, was built by Brazil and Paraguay jointly. It has 12.6 GW as its installed capacity.

The world's first pumped storage power station was built in Switzerland in 1879, which is called Lurton Pumped Storage Power Station.

1985, the pumped storage power station with the world's largest installed capacity, which is called Bath Visconti Pumped Storage Power Station, was put into operation in the United States.

The world's first tidal power station was built in 1913 by the coast of North Sea coast in Germany.

The greatest tidal power station was in France, it is called ‘Rance’, with installed capacity 240 MW.

In 1978, Japan built a wave power test boat called ‘Hamming’, and it was the world's first large-scale wave energy power station.

Introduction of two important hydro electrical power stations

• *Three Gorges Dam over Yangtze River [1]*

1. The Three Gorges is the world’s largest hydropower station, and it was also the largest construction of the project in China in that period.
2. 1994 began to build, 2003 began to generate power and 2009 totally finished.
3. The dam is 185 meters on height, 2335 meters on length.
4. The water level is 175 meters on height.
5. The length of the reservoir is more than 600 Km.
6. The total investment is 95.46 billion CNY.
7. The total capacity is 22.4 GW, and there are 32 units, each unit has installed power 700 MW.
8. Largest rate of flow: 100,000 Cubic meters per second.

9. The Three Gorges Power Station generates up to 98.8 TWh per year.

10. Every year, this station equivalents to reduce burning more than 49 million tons of raw coal and nearly one hundred million tones of carbon dioxide emissions are eliminated.

11. If we calculate each kWh of electricity as 10 CNY (1CNY ≈ 1 SEK in 2014) for China’s GDP, the clean electricity generated by the Three Gorges Dam equivalents of contributing 1 trillion CNY on GDP.

- **Compare the largest and second largest hydro power station [2]**

<table>
<thead>
<tr>
<th></th>
<th>The Three Gorges</th>
<th>Itaipu Dam</th>
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<tbody>
<tr>
<td>Size</td>
<td>largest</td>
<td>Second largest</td>
</tr>
<tr>
<td>Place</td>
<td>China</td>
<td>Brazil</td>
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<tr>
<td>Each Unit</td>
<td>700 MW</td>
<td>700 MW</td>
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<tr>
<td>Number of Units</td>
<td>32</td>
<td>20</td>
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<tr>
<td>Total Capacity</td>
<td>22.4 GW</td>
<td>14 GW</td>
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<td>Largest annual generation capacity</td>
<td>98.8 TWh</td>
<td>94.68 TWh</td>
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<tr>
<td>Height of dam</td>
<td>185 meters</td>
<td>176 meters</td>
</tr>
<tr>
<td>Length of dam</td>
<td>2335 meters</td>
<td>7744 meters</td>
</tr>
<tr>
<td>Height of the water</td>
<td>145-175 meters</td>
<td>1-3 meters</td>
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*(Table 1: The parameters comparison between the Three Gorges Dam and Itaipu Dam)*

The average power output of Three Gorges Dam has reached 84.7 TWh, but it was limited by the amount of water during the dry season. When wet season comes, it could use the endless rolling stream to generate more power. But because of the function of flood controlling, the water level would be reduced from 175 meters to 145 meters as table 1 shows, which resulted a lot of water has to be given up. So its average generation capacity was slightly less than the Itaipu power plant.

Itaipu is planned to generate electric power, so the height of water is always kept low. Table 1 shows the water level for Itaipu is usually at only 1 meter. Only in repairing, they keep the height of water in 3 meters.

China’s Three Gorges Project is planned to make flood controlling. Power generation is mostly based on the flood controlling aim. Therefore, it is much more
difficult to design than Itaipu. Its complex operating conditions can also be the most rare unit.

- *Niagara* hydropower station in USA

In 1897, the Niagara hydropower station, as the first 100,000 hp power plant, was completed. After that, more than a dozen large or small power stations had been built, the output of electricity was sufficient to supply the daily requirement of New York, Ontario and Canada. And now it is still working as usual, and is never stopped generating. It can be described as a science miracle in nearly one century of mankind history.

It was designed by the genius scientist Tesla in his thirties. Totally nine of his patented inventions were used in it, including the alternator and AC transmission technology invented by him.

In that period, public facilities and household appliances were all using expensive Direct Current. But because of the loss on the circuit, it is required to build a generator between each kilometer. So it was impossible to transmit the electricity to Buffalo, which is 35 kilometers far away from the generator, with DC.

So when it was build, the Americans adopted the AC generation and transmission technology which was invented by Tesla, and took the advantages of high-voltage power transmission technology to achieve the long-distance transmitting. This invention not only solved the long distance power transmission problems for Niagara power station, and also brought people into a convenient and cheap electricity environment. [3]

Advantages of Three Gorges Dam

- Renewable and clean energy
- High efficiency
- Low costs of generating
- Avoid flood

Disadvantages of Three Gorges Dam

- Huge investment
- Long construction period
- Limited capacity for single generator
Environment influence of Three Gorges Dam

- Effect the aquatic breeding
- Effect the route of waterway transport

The main functions of Three Gorges Dam

- Flood control

In history, the upstream of Yangtze river and its tributaries frequently cause floods during wet seasons. When huge flood came, we have to take measure to flood villages and farmland, in order to protect Wuhan City. But with the help of the dam, most floods can be retained in the reservoir.

- Power generation

The economic benefits of the Three Gorges project is mainly embodied in power generation. This project acts as a giant power source in supplying the main power consuming city groups in eastern China. The electricity will be mainly sold in 9 provinces located in central, east and south of China. It is able to alleviate the pressure from the main power consuming city groups in eastern China.

By the end of 2012, the Three Gorges Power Station had totally generated 629.14 TWh over the years. Compared with thermal power, this hydro power station equivalents to eliminate 496 million tons of carbon dioxide and 5.95 million tons of sulfur dioxide. It has made a positive contribution to energy conservation. [4]

- Shipping

Before the Three Gorges Project had been established, the up limit of annual one-way shipping traffic volume was 10 million tons. Besides, over 10-thousand-ton ships were not allowed to reach Chongqing City.

After several times of impoundment in the reservoir behind the Three Gorges Dam, the shipping environment has been improving. In 2009, the cargoes through the Dam had reached around 70 million tons.
The economical exploitation value and the developing level between China and some other countries in the world

There is not any formula for the developing level of the hydro power. However, if we refer the published data of the hydro power as the statistics parameters, more detailed, in our calculation, we divide the maximum exact value of generated power after 1998, by the value of the latest published technical or economical exploitation, thus we obtain the level of the exploitation of the hydro power for each country.

(PS: Due to the published data of the hydro power is contained the pumped-storage hydroelectricity and some other factors, there are some countries which get a higher than 95%, or even more than 100% score as the result. We combine them together as ‘over 95%’.)
In 2010, the total hydro generated power in the world is 3409.7 TWh, while the economical exploitation value is 8721.1 TWh. The hydro power takes 39% of the all kinds sources of power. Among them, the exploitation value for most developed countries are over 80%, while the value for developing countries are mostly below 30%. The economical exploitation level for Africa is 13%, and Asia (including Turkey and Russia) 34%, Oceania 49%, South America 45%, Mid and North America 66%,
and Europe (not including Turkey and Russia) 72%. The economical exploitation value for China is 1753.0 TWh, it is on the NO.1, and takes 20.1% in the whole world.

In 2010, the hydro generated power in China is 662.2 TWh, which occupied 19.42% in the whole world hydro generated power. And it also takes 16% of all kinds of power generated in China. The economical exploitation value is 38%. The average economical exploitation value for hydro power in developed countries is over 60%. In Germany, Switzerland, Spain and Italy, the actual hydro generated power takes up more than 95% of the economical exploitation value. And the percentage is 82% in the USA and 90% in Japan. If it is calculated with the technical exploitation value, then it is 74% for Germany, 92% for Switzerland, 67% for the USA, 86% for Italy, and 73% for Japan. For China, the proportion is only 27%.

Refer to the statistics result in 2010, there were 19 countries where the hydro generated power occupied over 90% in all kinds of power, like Norway, Paraguay and Albania etc. And 57 countries get an over 50% (including 50%) for hydro power, like Brazil, Canada, Switzerland and Austria etc. For over 40% of hydro power occupied, there are 64 countries, including most South American countries. The hydro generated power takes up 16% of all power generated in the whole world. Meanwhile the whole capacity of the hydro generators is 937,324 MW, while the capacity for the under construction hydro generators is greater than 185180MW. The capacity for the Three Gorges Dam is 22,500MW, the number one in the world.
Hydro power is generated by using electricity generators to extract energy from moving water. Historically people used the power of rivers for agriculture and wheat grinding. Today, rivers and streams are re-directed through hydro generators to produce energy, although there are pros and cons as far as local ecosystems are concerned. The articles on this page explore the use of water to generate electricity. (Reference source for Figure 3 [6])
The working theory of the generators

- **How does the generator work**

![Turbine Generator](image1)

(Figure 4: Model of turbine generator)

(Figure 5: Model of Turbine and generator)

In its simplest form, electricity is generated by rotating a magnet inside a wire coil. In a power station, this process is enhanced as figure 4 shows above: the magnet is an electro-magnet or “rotor” spinning inside the fixed coils or “stator” of the generator. Each generator is mounted on a vertical shaft above the turbine and figure 5 shows that water is used to drive the turbine, which operates the generator. Transformers boost generated voltage to a level that can be economically transmitted over long distances by transmission lines to the towns and cities of eastern mainland Australia.

The amount of electricity able to be generated depends primarily on the distance the water falls (head) and the volume of water (flow) regulated through the turbine.

The type of turbine used is determined by whether the water falls from a high, medium or low head. The Scheme’s power stations use Francis turbines, generally suited to medium heads. Francis turbines have guide-vanes and runners with fixed
blades. These guide-vanes control the volume of water required to drive the turbine and thereby determine the amount of electrical power produced.

• How do the generators sets cooperate

Introduction:
Hydro electric set is the equipment to convert potential power energy of water into electrical energy. [8]

(Figure 6: photo of generators inside Three Gorges Dam)

• The working principle: Rivers, lakes, etc. in high position have potential power, when water flows through the turbine, potential power is converted into mechanical energy, turbine generators also promote the mechanical energy into electrical energy.

• Hydroelectric generator set is driven by the turbine. Generator speed determines the output frequency of alternating current, therefore the rotor speed is crucial for ensuring stable frequency. Usually we take the closed-loop control mode to control the speed of the turbines, that means the frequency of the signal samples are taken from the alternating current, which is fed back to control the turbine guide vane closing angle control system to control the output power from turbines, so as to achieve the stability of the generator. Figure 6 shows the turbines’ control units in the Three Gorges Dam.
The basic formula and parameters for turbines \[^9\]

- **The basic concept**

The flowing water carries kinetic energy and gravitational potential energy. The turbine is the machine to transmit the energy contained in water into the electric power.

- **The working head**

There are two kinds of heads — Nominal productive head and Working head. The nominal productive head is used to describe the height of the water stored behind the dam. And the working head is the height of the water which is exactly used for generating the electric power. Which means, when we are talking about the depth of the water in the reservoir, it is about the nominal productive head, while we doing the calculation for the generated power, we obviously using the working head. Generally, we use $H_m$ to represent the nominal productive head, $H_G$ as the working head, and $H_l$ for the loss of head. Then we obtain: $H_G = H_m - H_l$.

(Figure 7: Schematic diagram)

- **Characteristic head**

Refer to the letters in figure 7, we get the following formulas:

The maximum working head:

$$H_{Max} = Z_{U(normal)} - Z_{D(min)} - H_l \quad (1)$$
where $H_{\text{Max}}$ is the maximum working head, $Z_{U(\text{normal})}$ is the normal level for upstream, and $Z_{D(\text{min})}$ is the minimum level for downstream.

The minimum working head:

$$H_{\text{Min}} = Z_{U(\text{min})} - Z_{D(\text{max})} - H_l$$  \hspace{1cm} (2)

where $H_{\text{Min}}$ is the minimum working head, $Z_{U(\text{min})}$ is the minimum level for upstream, and $Z_{D(\text{max})}$ is the maximum level for downstream.

The regular head, $H_r$, is the minimum working head for the turbine getting the regular output.

The average head,

$$H_{cp} = Z_{U(\text{ave})} - Z_{D(\text{ave})}$$  \hspace{1cm} (3)

where $H_{cp}$ is the average head, $Z_{U(\text{ave})}$ is the average level for upstream and $Z_{D(\text{ave})}$ is the average level for downstream.

- **Flow quantity**

  The flow quantity is the quantity of water flowed through the turbine in a unit time.

  The water quantity, $Q \text{[m}^3/\text{s]}$, is changed with the variation of the $H$ and $P$ for Power. When, the turbines are running in rated head and output power, $Q$ gets its maximum value.

  $$Q=f(H, P)$$  \hspace{1cm} (4)

- **Output and Efficiency**

  Output here is specially refers to the power transmitted to the generator from the turbine.

  \{Since the density of water, $\rho = 1 \times 10^3 \text{ kg/m}^3$, and the acceleration of gravity $g \approx 9.81 \text{ m/s}^2$, refer to $W_{\text{potential}} = mgH = \rho VgH = \rho QgHt$ (5), we obtain the following formula with unit [kW] \}

  Refer to formula 5, the input power for turbine (the energy from water to turbine) :

  $$P_I = mgH/t = \rho QgHt/t = 9.81QH$$ \hspace{1cm} (6)

  Where $P_I$ is the input power for turbine, $g$ is the gravity. ($Q$ and $H$ are the same as the value used in formula 4)

  Based on formula 6, we obtain the output power for turbine (the energy from turbine to generator) :

  $$P_O = 9.81\eta QH$$ \hspace{1cm} (7)
Where $P_O$ is the output power for turbine, $\eta$ is the efficiency of the turbine. ($Q$ and $H$ are the same as the value used in formula 4)

Efficiency:

$$\eta = \frac{P_O}{P_I} \times 100\% \quad (8)$$

Usually $\eta = 80\%$~$95\%$, since the loss in the head, the water quantity and the mechanical friction.

- **The torque and rotation speed**

  The output from turbine drives the axle of the generator, thus, the formula for the output also can be:

  $$P = M\omega = M(2\pi n)/60 = 9.81\eta QH \quad (9)$$

  Where $M$ is the torque for the main axle in generator, $\omega$ is the angular velocity of the turbine, $n$ is the rotation speed ([rpm], $n = 3000/p$ and $p$ is the numbers of the poles). $\eta$ is from formula 8.

  And here the result for formula 9 should be the same as the result for formula 7, which means the input power for the generator is just the output power for the turbine.

### Comparison of the capacity difference between a variety of generation methods

In 2014, the total national power generated is 5545.9 TWh, which had increased by 3.6% over the previous year. In classification: Hydropower generating capacity had reached 1066.1 TWh, increased by 19.7%, accounting for 19.2% of the national power generation capacity, which improved 2.6% higher than the last year. Nuclear power, wind power and solar power generation was 126.2 TWh, 156.3 TWh, and 23.1 TWh separately. [10]

### Electricity power generating proportion in China
By the end of 2014, the national power generation capacity was 1.360 TW, which increased by 8.7%. Among them, hydropower took 301.83 GW, accounting for 22.2% of the total installed capacity, thermal power was 915.69 GW, accounting for 67.4% of the total installed capacity, while the nuclear power was 19.88 GW, and wind power was 95.81 GW, solar energy generated 26.52 GW.

In 2014, the capacity of new-built power generation equipment was 103.5 GW, which added 21.85 GW on hydropower, 47.29 GW on thermal power, and 5.47 GW on new nuclear power, 20.72 GW on wind power, 8.17 GW on solar power. [10]

The power grid construction in China

By the end of 2014, the length of the national power grid transmission line loop for over 220kV was 57.20 thousand KM. Utility substation equipment capacity was 3.027 TVA, which respectively increased for 5.2% and 8.8%. [10]

Power transmission

In 2014, the whole power transmission quantity in China was 274.1 TWh, which increased 13.1%. The national inter-provincial electricity sent out 842 TWh, which increased 10.8%. [10]

Before Three Gorges Dam had been constructed, how did China grid regulate the grid frequency

Since China is such a big country, the grid is divided into two chief companies, State Grid corporation of China and China Southern Power Grid Company Limited. And each of them has some branches in different part of China and controls the grid for one or more provinces. As we mentioned above, each branch grid company will balance the frequency through PFR and/or SFR.

After Three Gorges Dam has been constructed, how does the China grid regulate the grid frequency? What does Three Gorge Dam act as on the frequency regulating in grid?

It is sad that the Three Gorges Dam did not stand in a very important place in frequency regulation. When this great project was just passed the vote by NPC
In 1992, the power request of the whole country is 747 TWh. The capacity of Three Gorges Dam power station is 22.4 GW, and the design average power generation per year is 84.7 TWh. In that period, it is around 11.34% of the whole request of power for China. But in 2013, the power request in China had risen up to 5322.3 TWh, and the exact power generated by Three Gorges Dam power station in 2013 is 98.1 TWh. The proportion is reduced to 1.8% after it fully went into operation. In 2013, the electric power used in Beijing City was 91.3 TWh, which means this great power station is only able to afford the power request for one big city in China.

On the other hand, the East-China Grid, which covered Shanghai City, Zhejiang Province, Jiangsu Province and Anhui Province, consumed the greatest volume of electric power. However, the Three Gorges Dam is not in this grid, what is more, the power transmission method between these two grid is HVDC. This project made China became NO.1 in HVDC transmission project. It means the Three Gorges Dam helped nothing on frequency regulation on the most important grid in China. Actually, in each grid in China, they still follow the AGC technique to control the grid frequency. And the Three Gorges Dam only helps the grid covered itself to control the frequency.

How does the power station keep the same frequency with the grid

The general frequency of AC in China grid is 50Hz. And as we know, the electric power comes from the generators, so the output frequency of the AC from all power stations in China is supposed to be 50Hz theoretically, which means the rotation speed of two poles generators should always keep 3000r/min, based on the formula: \( n = \frac{60f}{p} \).

Once the grid is built up, every power station will transmit the electric power in 50Hz to the grid. And it requires the rotation speed of each generator keeping 3000r/min. It is not a difficult challenge, since there is always a speed governor co-working with the generator. However, the it is the three-phase alternating current flowing in the grid. If the phase of AC from the generator is on top of sine wave, while the phase of AC in grid is just happened on the bottom of sine wave, it will lead a short circuit between the grid and the generator. In this situation, the easiest solution is making a tiny rotation speed difference, for example, 2999r/min in the generator. After half a minute, the phases from two sides will fit each other. Here we get a new question, will the short circuit happen after another half minute? The answer is 'NO' here. When there is a phase difference, the current comes out. This current from grid will flow to the generator and help it rising its rotation speed. Or if the rotation speed is higher than the grid required, the current flows from the generator to the grid and
reduces its speed. Finally, the grid with all generators connected with the grid will keep a dynamic equilibrium.

Now the grid and the generator have a synchronous frequency, but the phases might not be the same. It depends on the active power and the length of the lines (Capacitive Effect). Then let’s talk about the angle of the power. When the phase of AC from generator is beyond the grid, the generator transmit power to grid, otherwise, absorb power from grid. It is the relationship between active power with frequency and reactive power with voltage. We have another formula: \( P = \frac{M \times N}{9550} \) \( (M = \text{torque}, \ N = \text{rotation speed}) \). When the active power is increased from generator, which means the power angle is greater, the frequency will also rise. If the load of the grid is fixed, the frequency will exactly rise, but in the real situation, it will not happen. Because when the rotation speed increases, the loads get higher, which stops the rising of the frequency. And finally, the frequency comes into another balance, which is a little higher than 50Hz. [12]

How does the power station adjust when the frequency of the grid changes

When the frequency of the grid changes, the frequency regulation is required. And there are two ways to achieve that —— PFR (Primary Frequency Regulation) and SFR (Secondary Frequency Regulation).

Generally, PFR is based on the speed governor, all the generators in the system are joined in to make the adjustment. The system frequency are changed after regulation. So that PFR is also called Droop Regulation. PFR is focused on solving the frequency change led by frequently tiny fluctuation of loads in the grid, which is finished by the speed governor. It will change the output power for each individual generator in order to fit the change of their loads. PFR runs automatically and only helps to reduce the fluctuation of frequency in the grid, but it cannot eliminate the frequency change. [13]

The main part of SFR is the frequency regulation plant, which means only the generators which are working on frequency regulation join in. It is based on the synchronizer and manually control the loads for the generators above, in order to balance the grid frequency. And it is also called Non-droop Regulation.

Basically, there are two methods to make the SFR: [14]

1. The chief plant gives the order to the branch plants, and the branches make the adjustment from the order.
2. The generating units follow the order from AGC (Automatic Generating Control), and adjust the loads for each individual generator automatically.
Flexible AC Transmission Systems

Shunt FACTS devices such as static VAr compensators (SVCs) can improve voltage control particularly in regions where old generation assets are being retired leaving large load pockets with little to no dynamic reactive support in the immediate vicinity. Another family of static compensators (STATCOM) is based on voltage source converter technology. It presents additional benefits since once at its reactive limit a STATCOM is a constant current device, while an SVC tends is a constant impedance device. Fast automatic switching of large shunt capacitor banks can also improve voltage stability.

Series devices such as thyristor controlled and conventional series capacitors improve transient stability margins on long extra-high voltage transmission corridors. More traditional devices such as phase-shifting transformers can also often be applied for controlling power flow on parallel paths.

Technologies such as Unified Power Flow Controllers (UPFC) can also control power flow on parallel transmission corridors. [15]

High voltage DC

HVDC voltage source converters (VSC) allow independent controllability of active and reactive power and his type of HVDC system can black-start an islanded region of the system and can be applied in very weak systems. Due to the controllability of power flow, an HVDC system will not be overloaded in an emergency system condition, which significantly reduces the risk of cascading outages. Reactive power control, available with VSC, also improves voltage regulation and control and thus improving system stability by reducing the risk of voltage collapse. [15]

Comparison the technique between HVDC technology and AC transmission

- Advantage of HVDC

1. HVDC has no stability problems in synchronous operation between the two ends of the AC system. Its transport energy and distance is uncommitted by the limitation of synchronous operation.
2. It is easy to use HVDC interconnection for Partition scheduling management
3. HVDC control system responses quickly, adjusts accurately, is easy to operate, and which can achieve multi-objective control.
4. HVDC transmission line has a smoothy voltage distribution, and there is no capacitive current, with no need for compensation of shunt reactors, which reduced the cost for construction.
5. HVDC transmission equipments are able to be constructed grading and staging, which is easier to make the capacity expansion.

- **Disadvantages of HVDC**

1. Inverters will consume more reactive power when it is working
2. The overload energy of thyristor elements are low.
3. When DC transmission use land or sea as reflux circuit, it will cause the corrosion to the metal facilities underground or in seawater, while also bring interference to communication and navigation.
4. It is more difficult for arc extinguishing in HVDC, since there is no zero crossing points in the current waveform for DC.

The economy comparison between HVDC and AC transmission

- **HVDC has lower investment in overhead line**

HVDC usually use the Bipolar neutral grounding way, DC line only needs two wires, and three-phase AC circuit needs at least three wires. But they have the same delivered power. Thus, the HVDC transmission reduces the loads of the towers and the width and area of line corridor. When the deliver power and distance are the same, the cost for HVDC overhead lines is two-thirds of the three-phase AC circuit.

- **Less investments in DC cable lines**

The allow working voltage of the same cable insulation for the HVDC is twice higher than used for AC transmission. So when they meet the same voltage, the cost of HVDC cables are much lower than AC cables.
• **The investment for converter station is greater than the substation**

The equipments in converter stations are more complex than AC substation. Besides the converter transformer, and there are also SCR converters, which are now expensive. With other necessary ancillary equipments, in the same capacity and the same voltage, the converter station costs more than the substation.

• **Less operating costs**

Depending on the operating experience in some pioneer countries, the maintenance cost of lines and equipments is broadly similar in AC and HVDC. But under two conditions (Electric energy loss in the same wire section, transmission of active power), the HVDC power loss is two-thirds of AC transmission.

Many countries now have a successful trial of the DC circuit breaker and load switch, and is studying the combination of these control switching devices and HVDC technology to achieve MTDC (Multi-Terminal HVDC).

### Distribution of the grids in China

• **The main grids in China**

As we mentioned above, there are 2 main corporations manage the grid in China. And here we would like to introduce how the grid is distributed with these two corporations in China with the help of figure 8.

1. **State Grid Corporation of China.** It is made up by 5 branch corporations — North China Grid Company Limited (Beijing, Tianjin, Hebei, Shanxi, Shandong, North Hebei), Central China Grid Company Limited (Hubei, Hu’Nan, Jiangxi, He’Nan, Sichuan, Chongqing), East China Grid Corporation (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian), Northwest China Grid Company Limited (Shanxi, Gansu, Ningxia, Qinghai, Xinjiang, Tibet) and Northeast China Grid Company Limited (Liaoning, Jilin, Heilongjiang, Inner Mongolia). It was set up in 29th Dec. 2002, and now is the greatest corporation on utilities. The business of this company covers 26 provinces in China, which is roughly 88% area of China. Based on this, it offers the electric power to more than 1.1 billion people.

2. **China Southern Power Grid Company Limited.** It is also made up by 5 branch corporations — Guangdong, Guangxi, Yunnan, Guizhou and Hainan branch grid company limited. However, there are only one grid, the South Grid, which covers all these 5 provinces above. This company was set up in the same date as the State Grid Corporation of China, 29th Dec. 2002. The establishment of
this company was a great breakthrough on reform of the electric system in China.

(Figure 8: Distribution map of China grids)

- **The main high voltage transmission lines in China [16]**

In the Twelfth Five-year Developing Plan for China (2011 - 2015), one of the main aims is establishing a synchronized national grid, which should take the East, Central and North China Grid as its core, and well connect the the rest China Grids. In order to achieve it, the government will invest 260 billion CNY on Ultra High Voltage AC, and 230 billion CNY on HVDC as well. The chat below shows the power transmission lines which have been or will be established in China. Figure 9 and table 3, 4 show the distribution of the high voltage transmission lines in China.
• Ultra-High Voltage means the transmission voltage is higher than 1000 kV
• NOM means Not On Map, which means they are probably the branches for the huge national synchronized grid.

(Table 3: Ultra-High Voltage AC transmission lines in China)
The cities in brackets are the cities on map which are near the starting or ending cities in the sheet.

(Table 4: HVDC transmission lines in China)

<table>
<thead>
<tr>
<th>Route</th>
<th>Start</th>
<th>End</th>
<th>Voltage level (KV)</th>
<th>Capacity (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qinghai - Tibet</td>
<td>Ge’ermu (NOM)</td>
<td>Lassa (NOM)</td>
<td>±400</td>
<td>0.6</td>
</tr>
<tr>
<td>Three Gorges - Shanghai</td>
<td>Jingmen</td>
<td>Fengjing (Shanghai)</td>
<td>±500</td>
<td>3</td>
</tr>
<tr>
<td>Binchang - Shandong</td>
<td>Binchang (North Shaanxi)</td>
<td>Linxi (Ji’nan)</td>
<td>±660</td>
<td>4.6</td>
</tr>
<tr>
<td>Xiluodu - Zhejiang</td>
<td>Xiluodu (Leshan)</td>
<td>West Zhejiang (North Zhejiang)</td>
<td>±800</td>
<td>7.5</td>
</tr>
<tr>
<td>Jiuquan - Hu’nan</td>
<td>Jiuquan (NOM)</td>
<td>Xiangtan (Changsha)</td>
<td>±800</td>
<td>7.5</td>
</tr>
<tr>
<td>Humeng - Shandong</td>
<td>Humeng (NOM)</td>
<td>Qingzhou (Ji’nan)</td>
<td>±800</td>
<td>7.5</td>
</tr>
<tr>
<td>Ximeng - Jiangsu</td>
<td>Ximeng</td>
<td>Taizhou (Nanjing)</td>
<td>±800</td>
<td>7.5</td>
</tr>
<tr>
<td>Jinping - Jiangsu</td>
<td>Jinping (Chongqing)</td>
<td>South Jiangsu (Nanjing)</td>
<td>±800</td>
<td>7.2</td>
</tr>
<tr>
<td>Hami - He’nan</td>
<td>Hami (NOM)</td>
<td>Zhengzhou (Zhumadian)</td>
<td>±800</td>
<td>7.5</td>
</tr>
<tr>
<td>Baoqing - Tangshan</td>
<td>Baoqing (NOM)</td>
<td>Tangshan (Beijing North Tianjin)</td>
<td>±800</td>
<td>7.5</td>
</tr>
<tr>
<td>West Inner Mongolian - Jiangsu</td>
<td>West Inner Mongolian (NOM)</td>
<td>Liyang (Nanjing)</td>
<td>±800</td>
<td>7.5</td>
</tr>
<tr>
<td>East Gansu - Jiangxi</td>
<td>East Gansu (NOM)</td>
<td>Xinyu (Nanchang)</td>
<td>±800</td>
<td>7.5</td>
</tr>
<tr>
<td>Huaidong - Chongqing</td>
<td>Huaidong (NOM)</td>
<td>Chongqing</td>
<td>±1100</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Compare with the information in figure 9 and table 3 with table 4, we have found that not all transmission lines are on the map, and some of the lines drawn on map are not in these two tables. It is because the routes and voltage levels of some lines on map have still not been decided yet, and some routes in tables are not the main lines in constructing the synchronized national grid. With the confirmed routes above, we can still get some valuable information.

There are two electric power bases in China. One is for thermal power stations, which is in north China grid (figure 8), surrounded by Ximeng, North Zhangjiajie, North Shanxi and North Shaanxi (figure 9). And the other one is for hydropower stations in central China grid (figure 8), around Ya’an, Leshan, Chongqing and Jinmeng (figure 9). And actually they roughly follow the path of the Yangtze River and first 3 largest hydropower stations (table 2) of China are located in this hydropower base.
The differences between the distributions of UHVAC and HVDC lines illustrate that the UHVAC lines are more used in thermal power while the HVDC are more constructed in hydropower. And when the power transmission lines go through big cities with more than 5 millions of population, they are generally chosen as UHVAC lines. On the contrary, when the power transmission lines are going directly from power base to the main power consuming cities or city groups, they are generally constructed in HVDC lines. It is an apparent case on the characteristic differences between UHVAC and HVDC. Most power transmission lines which go through big cities are supporting the electric power for these cities. Since the converter stations are more expensive than the substations in same scale, and the distance between cities in the same province is not that long, UHVAC transmission lines are more suitable here. When the electric power is only required to be transmitted from the power base to other grids or main electric power consuming cities, it is usually a long trip. For example, in figure 9 and table 4, from the Three Gorges Dam to Shanghai and from Xiluodu (the second largest hydropower station in China) to Zhejiang, the electricity should be transmitted through even more than half China, which is over 2000 km. And this electricity is specially supporting the main cities in East China Grid from Central China Grid, thus HVDC is quite a superior choice here.

Earthquake and Freezing troubles for grids

- **For the earthquake**

1. The newly built nodes and net structures should be able to support each others with new or original equipments. For the important clients (for example the command center), two or more access points are necessary. In that case, we make it sure that at least one line is able to offer power for them.

2. The power sources are supposed to be dispersed as possible. We never know where would the earthquake shock, so that if the power sources are distributed dispersed, the probability of the massive cases of the power sources disconnected with the grid. And the addition, each city is asked for a ‘Black Start’ power source, which helps a lot for improving the ability to facing the extreme situations like earthquakes.

3. The transformer substations in the high-risk areas are not planned to construct in a great scale. In stead, they are supposed to be settled separately.

4. Besides the convenient and economic thinking, all equipments are distributed away from the Earthquake fault Area. If it cannot be achieved, then the equipments inside this area should be designed as the top level of the seismic standards. And the transmission lines are all built upon the free-standing towers, in order to improve the seismic capacity.
5. In the high-risk area, the power distributor are suggested to use the Suspensory tubular bus-bar with the normal middle scale distribution. The equipments are required in low position of the gravity center with light top part. Use the vertical hose of the transformer instead of the pitched one. And the shield is better to use the silicone rubber.

6. The lines between two equipments should be a little bit longer than normal designed in high-risk area.

7. All the main equipments, such as the breaker, the transformer, etc, are required to distributed over the rubber bearing.

- *For the freezing*

In Hunan province: 485 equipments are deployed —— 375 automatic Icing monitoring forecasting systems, 28 melting equipments for main AC/DC net, 59 melting equipments for countryside power net, 21 heating deicing cars, with 2 Four-rotor UAV inspections. [17]

### Blackouts and their impacts

The term blackout is used to describe a widespread cutoff or loss of supply of electrical power, especially as a result of a shortage, a mechanical failure, or overuse by consumers. It is well known that blackouts happen only rarely and they are usually caused by a sequence of low probability outages. Common electric power system design practice strives to have the system remain functional for contingency and not for the sequence of low probability disturbances. Most disturbances associated with major blackouts have occurred following a series of successive unscheduled equipment outages beyond subsequent to the occurrence of extremely low-probability events. Blackouts are caused by a variety of phenomena. The causes include weaknesses in the infrastructure, storms, the general climate and human error. The consequences can be far ranging: disruption to industry, transport problems and a variety of social and political effects. [18]
Analysis

• The status quo of Three Gorges Dam

By the end of 2014, the China national power generation capacity was 1,360 TW. Among them, hydropower took 301.83 GW, accounting for 22.2% of the total installed capacity. Besides, in the form of TOP 20 DAM IN THE WORLD, 12 dams are in China, and there are also many small dams which are not in the form. So it is very obvious that hydro power in China has been well developed. But due to the huge population, hydro power is not enough. Thus, other kinds of generation such as thermal power and nuclear power have to be built, which makes hydro power accounts for only 22.2%. But compared with other countries, 301.83 GW is still a quite huge quantity of capacity.

• Efficiency and environment thinking of hydropower

Refer to the data above on page 9, the Three Gorges Power Station distributed 32 generation units with 700MW capacity for each, and the total capacity reaches 22.4GW. The general thermal turbine capacity is 600MW and the greatest thermal generator in China is in 5GW. From the difference between the installed capacity, the Three Gorges Power Station is over 4 times than the greatest thermal power station. And in 2014, the Three Gorges Power Station generated 98.8 TWh of electric power, however, the greatest thermal power station generated 27.5 TWh of electric power per year. Which means when the Three Gorges Power Station was established, 3.5 thermal stations in the largest size would be replaced. It also means that over 4900 tons of coal has been saved, and it avoids the emission of carbon dioxide approaching to 100 Mt. It is a huge move on environmental protection. What is more, the energy conversion efficiency by hydro turbine is exceedingly higher than the thermal turbine: the efficiency for hydro turbine is generally over 75%, and the efficiency for large-scale hydropower station is able to reach as high as 90%, while the upper limit for the thermal generator is only 60%, and in real practice, it is usually 40%. For hydro power, the energy is only transformed 2 times: kinetic energy or potential energy in water to mechanical energy in turbines and electric power at last. Then the thermal power, the energy should be transformed in 3 steps: chemical energy in fuel to internal energy in steam to mechanical energy in turbines and finally electric power. Thus hydropower is obviously much more clean and efficient.

• The significance of constructing national grid

When the grid has been constructed, it becomes much easier to transmit and manage the electric power than ever before. With the help of the national grid which has covered all provinces in China, the lack of electric power in some provinces would never be a problem on obstructing their development. Once the power
generated inside its province is not enough for itself, it is easy and convenient to ask the extra power from the other provinces inside the same grid. Similarly, if the power consumed in this grid exceed what it is able to generate, the other grids are able to support it with HVDC or UHAC transmission lines which are connected to each grids. Furthermore, since the grids has covered all the mainland China, it is able to get enough electric power for some lonely towns and cities without generation stations. Inside the grid, if anything happened which would lead a blackout, it would only be limited inside this grid but never spread to the nearby grids. Since there are plenty enough transformer substations in each grid, the blackouts will also limited in a small part of the grid. And some kinds of blackouts which are caused by the malfunction in the power stations will not result to a regional power off, because the electric power from other power station can be transmitted to these areas. The grid is also a great solution for the trouble that the energy bases are not coincided with the city bends which requires the most energy.

**Conclusion**

With all statements above, we have had a clear thinking about how the mechanical energy contained in water is transformed to electric power and finally transmitted into every electric power consumers.

As the largest hydro engineering, the Three Gorges Power Station played an important role in the clean energy field. Hydro generation is the most efficient among all methods up till now, and it is also a pure clean energy with zero pollutions. With the tendency goes through, the clean energy takes a more and more important position. If it will not take a huge change for the surroundings, it should be fully supported to construct a hydropower station in order to fully use the clean and free energy. With the development of the grid, the location of the power station can even be ignored in the future, thus, it is much easier to distribute the hydropower station.

The national grid has almost been constructed in China in most main city groups. Since the ‘smart house’ goes from an idea to the real life, the ‘smart grid’ should be expected as well. The smart grid should be able to adjust the frequency in the grid automatically. Then it can be more flexible for the power source accessing to the grids. Based on them, the smart grid would run more stable, and the managers with clients will never worry about the fluctuation of the voltage or blackouts and so on. It will be a great project after the national grid would have been finished. We are looking forward to meet the smart grid as soon as possible!
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