Applied Energy Symposium 2021: Low carbon cities and urban energy systems
September 4-8, 2021, Matsue, Japan
Paper ID: 27

Palliative or Surgery： Thermal Power System and Battery Energy Storage System in Supporting Low Carbon Transition in China

Boqiang Lin[1], Zhiwei Liu [2*]

1 School of Management, China Institute for Studies in Energy Policy, Collaborative Innovation Center for Energy Economics and Energy Policy, Xiamen University

2* School of Management, China Institute for Studies in Energy Policy, Collaborative Innovation Center for Energy Economics and Energy Policy, Xiamen University

ABSTRACT

With the goal of carbon neutrality, low carbon transition is necessary in China. it is a common sense that there will be more RES(renewable energy sources) and thermal power will quit the main stage of power supply. RES will bring volatility to power system and threaten its reliability. Thermal power with flexibility modification and BESS(battery energy storage system) are two ways to ensure the safety of power system. This study provides a model on level of hour to calculate and analyze cost of power system in different penetration rates of RES. A province in China is taken as an example to compare flexible thermal power with BESS in five scenarios. It is found that thermal power with flexibility modification has an obvious advantage over BESS in short term while BESS is more potential in long term. An opinion for future of power system is given: thermal power still has a lot of things to do and it will quit by stepwise decreasing available hours instead of abandon of existing units in short term, BESS will play a more important role in long term.

Keywords: thermal power, flexibility modification, BESS, penetration rates of RES, available hours

NONMENCLATURE

Abbreviations	
RES	Renewable Energy Sources
BESS	Battery Energy Storage System
LCOE	Levelized Cost Of Electricity
Symbols	
n	Year
a	coefficient for calculation of cost
b	coefficient for calculation of cost
c	coefficient for calculation of cost
N(P)	rotor cracking times of thermal power units
P	capacity in operation of thermal power units
pa	demarcation point of BPR and DPR
pb	demarcation point of DPR and DPRO
pc	minimum load level of thermal power units
Qoil	amount of oil needed for thermal power units in one hour
β	loss coefficient for DPR

1. INTRODUCTION

Carbon neutrality has drawn more and more attention in China since President Xi announced that China aims to "have CO2 emissions peak before 2030 and achieve carbon neutrality before 2060" via video link to the General Debate of the 75th session of the United Nations General Assembly on September 22, 2020. The most suitable way for China to achieve the goal of carbon neutrality is a topic worthy of studying.

China has an energy structure with high rate of fossil energy. Thermal power generators provide 68% of total electricity consumption in 2020. Wind power and photovoltaic power have a proportion of 21% in installed capacity while only 11% in electricity production. Goals like "Carbon Neutrality" need an energy structure with a higher renewable energy rate. More RES bring more volatility to power grids, while reliability and safety of power supply are primary mission in China. Government will always ensure the power supply without regard to cost. So there need to be some solutions to deal with the volatility brought by RES, meanwhile lowering the cost as far as possible.

Selection and peer-review under responsibility of the scientific committee of CUE2021

Thermal power with flexibility modification and BESS are two ways to support low carbon transition of power supply. Thermal power is thought to be abandoned by some researchers for its carbon emission. While there're some specific conditions in China making it unreasonable to discard thermal power immediately. BESS is highly praised by many researchers for its performance in regulation service of power grid. But disadvantages like unacceptable cost has limited its expansion.

In view of situations above, taking a province of China as an example, this study mainly compares the feasibility of thermal power with flexibility modification to that of BESS in different penetration rates of RES. The discussion is mainly around economy and viability. It is found that flexibility modification for thermal power is more like palliative while BESS is surgery to low carbon transition of power supply in China. Though thermal power is bound to quit, it is still irreplaceable in the way to carbon neutrality of China. It is more reasonable to lower the available hours of thermal power stepwise instead of abandon most of existing thermal generators at once. BESS will be valuable in long term when there was an acceptable cost.

2. PAPER STRUCTURE

2.1 Subdivision - numbered sections

The following papers are mainly divided into these parts: 2.2 is a brief introduction of the study including objectives and possible contributions of the work; 2.3 provides sufficient details of data and methods used in the study; 2.4 shows theories and framework of calculation; 2.5 contains results and discussion. 2.6 presents main conclusions. 2.7 lists reference of the work.

2.2 Introduction

Facing the goal of carbon neutrality, it has been common sense that RES will take the place of fossil energy to be the main force of power supply. When dealing with disadvantages of RES such as volatility and intermittent, there are usually two solutions which are flexibility modification for thermal power and BESS.

China has the largest scale of deployment of thermal power in the world, there are capacity of over 1250 GW installed up to 2020. Besides, thermal power in China is one of the most advanced in technology level all over the world. Supercritical and ultra-supercritical power generation takes main part of thermal units in capacity. Most of thermal units are still very young in China, they have an average service life less than 12 years. In short, thermal power in China is large-scale, advanced and young.

Thermal power guarantees a reliable power supply for a long time in China with its stability and low cost coming from resource endowment of coal. Meanwhile, benefited from adequate deployment all over the nation, thermal power also plays the role of regulation service in power grid. Recently, flexibility modification has brought more possibilities for thermal power when dealing with a higher penetration rate of RES. Policies and subsidies for thermal power participating in deep peak regulation services have been more and more reasonable which provides more motivations for thermal power to change its role in power structure.

BESS has remarkable advantages in flexibility and convenience, there are nearly no additional emission and cost during its operating. Large-scale BESS is considered as solutions for maintaining safety and reliability of power grid in future. For now, high price of battery makes it impractical in supporting low carbon transition.

Objectives and possible contributions of the study are as follows: (a) providing a model to calculate the cost of power units with different penetration rates of RES, (b) compare the cost and feasibility of flexibility modification for thermal power and BESS in several

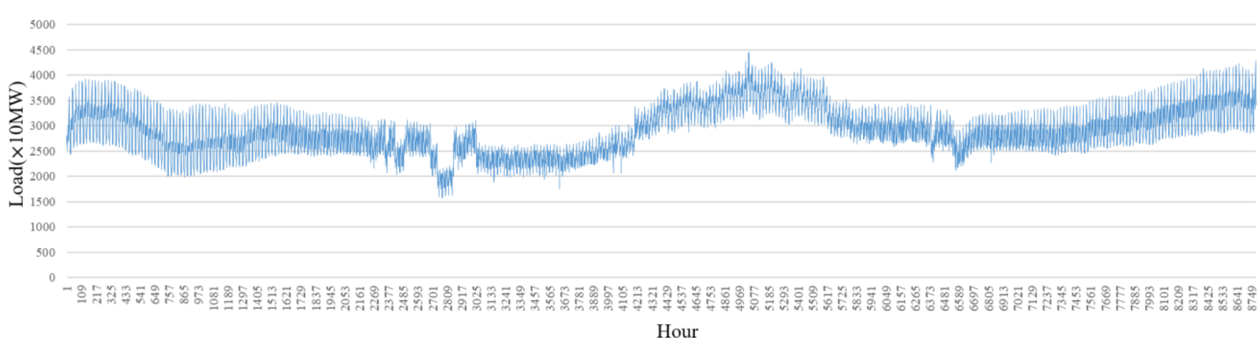

Fig 1 Load curve over a year

specific scenarios, (c) providing a reasonable solution for thermal power and low carbon transition in China.

2.3 Material and methods

The calculation model in the study is based on load curve in Anhui, a province of China. Using the data from National Statistics Bureau in 2020, there are 8784 points in load curve. Fig 1 shows the curve of corrected load over the year.

Basic scenarios are set referred to data from National Statistics Bureau in 2020. Consumption of electricity is 242.75 billion kWh; production of electricity is 268.16 billion kWh. Installed capacity of thermal power is 55.4 GW, account for 73.84% of power supply; Hydro power has an installed capacity of 3.84 GW which accounts for 5.12%; Wind power and PV power have installed capacities of 2.88 GW and 12.91 GW accounting for 3.84% and 17.2%. It can be seen that Anhui is a province with high rate of thermal power in power supply which is same as situation in whole nation.

2.4 Theory/calculation

2.4.1 Framework

Fig 2 shows the basic logic of the framework. Five scenarios bring specific boundary conditions to load curve, with consideration to some rules like ensuring of maximum demand and minimizing cost. Production of thermal power and BESS which are considered as flexible power supplies will be calculated by rules above, then with further limits like ensuring safety operation of thermal units, there will be an operation scheme of thermal power and BESS by which cost and other parameters can be analyzed.

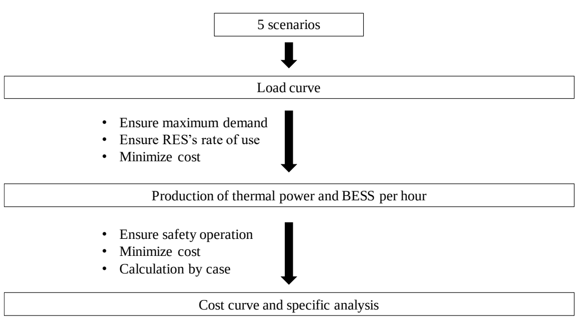

Fig 2 Framework of calculation

Five scenarios are set according to objectives of the study. Five scenarios are set according to objectives of the study. (1) normal flexibility modification; (2) extreme flexibility modification; (3) BESS with high cost (¥5000/kW); (4) BESS with middle cost (¥3000/kW); (5) BESS with low cost (¥1500/kW). Regulation capacity of thermal power is different in Scenario 1 and 2 which will be explained in 2.4.3. Thermal power in scenario 3, 4 and 5 is set without flexibility modification to make the contrast more significant.

Fig 3 shows the scenarios. P_i means electricity production that thermal power and BESS need to deal with, it is calculated by known total production, known production of hydro power and specific set production of wind and PV power.

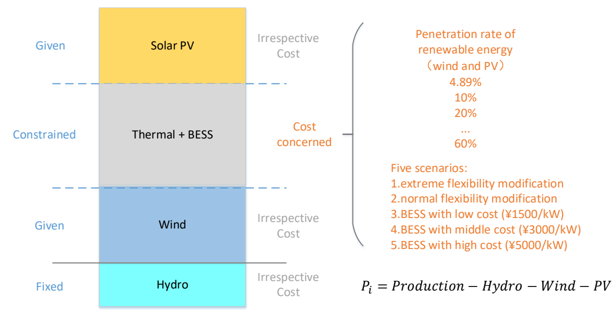

Fig 3 Scenarios in the study

2.4.2 RES units

The main concern of the study is comparison between thermal power and BESS when dealing with penetration of RES, so it is reasonable to utilize RES as far as possible.

Hydro power in Anhui will remain stable in future in view of resource endowment and increasing boundary cost. Considering that hydro power mainly varies between seasons instead of days, production of hydro power is calculated as follow:

$$hydro_i = \frac{hydro_{month}}{24 * days_{month}}$$

$hydro_i$ means production of hydro power in each hour, $hydro_{month}$ represents production in the month and $days_{month}$ means number of days in the month. Fig 4 shows monthly production of RES.

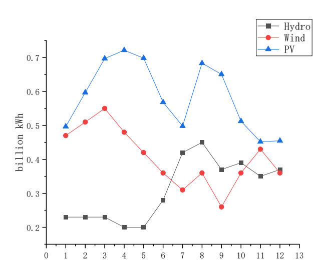

Fig 4 Monthly production of RES

Wind power and PV power have hourly variation as well as seasonal difference. Daily typical curve is introduced referred to existed research[1-5] in addition to monthly curve of production. Production of wind and PV is calculated as follows:

$$wind_i = typicalcurve_i \times \frac{wind_{month}}{days_{month}}$$

$$pv_i = typicalcurve_i \times \frac{pv_{month}}{days_{month}}$$

$typicalcurve_i$ represents level of production in the hour of a day. Fig 5 shows hourly typical curve of wind power and PV power.

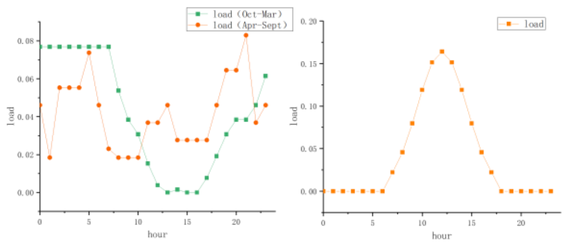

Fig 5 Scenarios in the study

2.4.3 Thermal units

To ensure the safety and stability of power grid, installed capacity of thermal power is set to be at least larger than maximum hourly loud in one year.

Operation state of thermal units can be divided into 3 stages by level of load. As shown in Fig 6, there is basic peak regulation, deep peak regulation and deep peak regulation with oil. Total cost of the units will first decrease for less fuel needed, then there will be additional cost coming from depreciation on stage of deep peak regulation, significant additional cost will come from oil used when level of load decreased further.

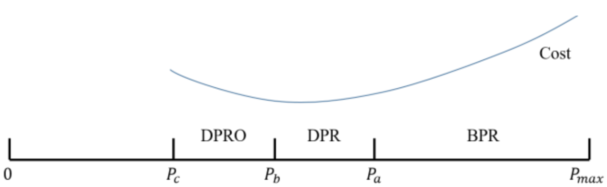

Fig 6 Stages of thermal units

Cost of thermal power units can be calculated as follows according to previous researches[6-14]. Parameters below are listed in the table in front part.

$$cost = \begin{cases} cost_{coal}\ ,\ BPR \\ cost_{coal} + cost_{loss}\ ,\ DPR \\ cost_{coal} + cost_{loss} + cost_{oil}\ ,\ DPRO \end{cases}$$

$$cost_{coal} = (aP^2 + bP + c)p_{coal}$$

$$cost_{loss} = \frac{\beta cost_{unit}}{2N(P)}$$

$$cost_{oil} = Q_{oil} \times p_{oil}$$

$$N(P) = 0.005778P^3 - 2.682P^2 + 484.8P - 8411$$

In scenario 1, cost of thermal power is calculated as above, in scenario 2, extreme flexibility modification will get rid of oil cost even in DPRO. In scenario 3-5, thermal units can only run on stage of BPR.

2.4.4 BESS

BESS will be used only during peak and valley time, in view of that our concentration is comparison between thermal power and BESS, only the capacity and capital cost is taking into consider here.

With consider to the safety of power grid and avoiding waste of energy, capacity and cost of BESS are calculated as follows:

$$\begin{cases} C_{thermal} + C_{BESS} \geq Load_{max} \\ \frac{P_a}{P_{max}} C_{thermal} - C_{BESS} \geq Load_{min} \end{cases}$$

$$cost_{BESS} = capacity_{BESS} \times price_{BESS}$$

2.5 Results and Discussion

2.5.1 Cost

Fig 7 shows total costs of five scenarios in different penetration rate of RES.

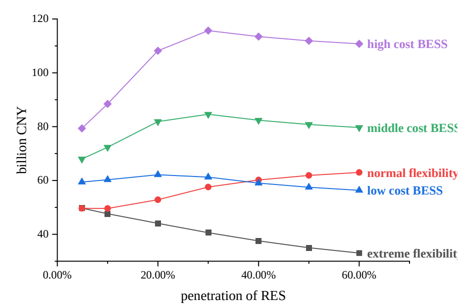

Fig 7 Cost curve of five scenarios

It can be seen from the cost curve that thermal power with flexibility modification is a cheaper way for adoption of RES in scenarios set in the study. Different level of flexibility modification have disparate trend in cost when penetration rate of BESS increase. While BESS shows something good when RES takes a considerable part in power structure.

Fig 8 shows LCOE (levelized cost of electricity) of flexible power consisting of thermal power and BESS (if exist) and the whole power supply. It can be concluded that levelized costs of the two ways show disparate growing trend with increase of penetration rate of RES. Thermal power with flexibility modification is more competitive in short term when penetration rate of RES is low, while BESS will be superior in long term when RES take over the main part of power supply and cost of BESS decrease.

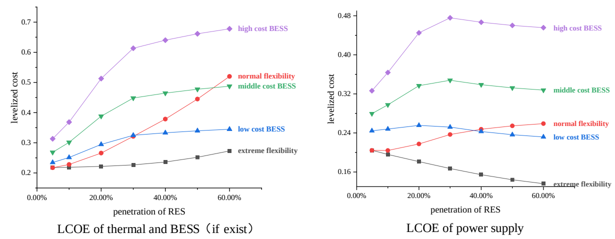

Fig 8 LCOE curve

To find out the inner mechanism of the cost, Fig 9 shows costs of scenario 1 and 5 in detail. It can be concluded that Difference in trend comes from inner mechanism. Cost from oil in thermal power will have a remarkable increase. In short term, thermal power with flexibility modification is more like some kind of palliative. While in long term, it just cures the symptoms, not the disease. BESS works once and for all.

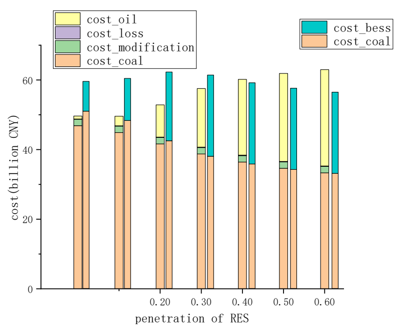

Fig 9 Costs in detail

2.5.2 Operating state

How thermal power and BESS work and what their operating state are also means a lot as well as costs. Installed capacity and available hours of thermal power and BESS are shown as Fig 10.

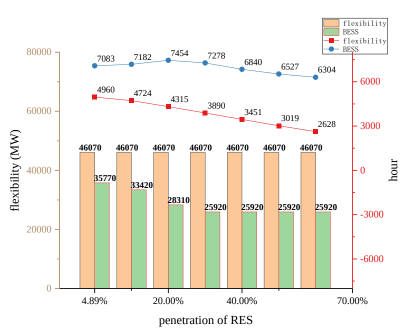

Fig 10 Capacity and available hours

It can be seen that thermal power with flexibility modification can make use of existing large amount of thermal power units and it will lead to a stepwise decrease of available hours. BESS will keep a high level of available hours for thermal power units, but there will be a sharp cutoff in installed capacity of thermal power. In view of current situation, it is obvious that thermal power with flexibility modification is more feasible in short term.

Fig 11 shows hours of different stages on which thermal power runs over a year. It shows that DPR will be normalization for thermal units with increase of penetration rate of RES. Hours of minimum level of load will increase rapidly, this state of operation will lead to waste of power and serious loss of units. In conclusion, thermal power with flexibility modification will show its disadvantage when RES became main force of power supply.

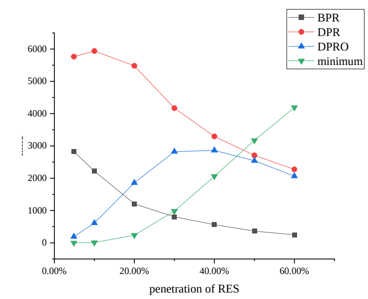

Fig 11 Operation state of thermal power

Fig 12 shows installed capacity and its proportion in power supply, there is also using conditions of BESS. BESS has limited capacity share and available hours when penetration rate of RES is low. There is a maximum capacity which will be necessary for energy system. Regulation demand from valley time will be much more than that from peak time when penetration rate of RES is high.

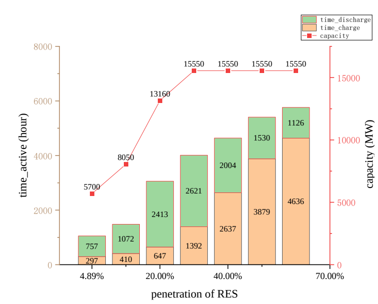

Fig 12 Operation state of BESS

2.6 Conclusions

The main conclusions of the study can be presented as follows:

(1) In short term, thermal power with flexibility modification has an advantage over BESS in view of both economy and feasibility.

(2) Flexibility modification can provide a way to survive for existing large amounts of young units. BESS

will bring a sharp cutoff in installed capacity of thermal power.

(3) BESS will have competitiveness only if penetration rate of RES reached a high level and cost of BESS decrease to an acceptable level.

(4) Stepwise decreasing available hours and flexibility modification is the most reasonable way for thermal power, though the destination has been clear, there are still a lot of things it can do.

Several policy implications are provided according to the conclusions of the study:

(a) Complete and optimize relevant policy and standard of flexibility modification for thermal power stations. Provide a more comfortable environment for transition of thermal power.

(b) Introduce relevant subsidy scheme for thermal power units participating in regulation and ancillary service market, consider decreasing available hours of thermal power units in particular. Motivate relevant thermal power stations to carry on flexibility modification as soon as possible.

(c) Try to control the technical level of flexibility modification, carry on the pace of shutting down outdated and scattered thermal power units. Lower cost comes with higher technical level.

(d) Slow down the pace of BESS's spread for its extravagant cost. Focus more on flexibility modification of thermal power stations. Wait for an appropriate time when cost of BESS is acceptable and penetration rate of BESS is considerable, then transfer the focus from thermal power to BESS.

2.7 Further discussion

This study mainly concentrates on comparison between flexible thermal power and BESS, model for calculation here is set based on the goal. Thermal power and BESS here entirely run as planned. While there will be competition between each thermal power station and BESS unit, they will choose different strategy for operation. For further study, it will be more reliable if game between power units was considered.

REFERENCE

[1] Tascikaraoglu, A. and M. Uzunoglu, A review of combined approaches for prediction of short-term wind speed and power. Renewable and Sustainable Energy Reviews, 2014. 34: p. 243-254.

[2] Gallego-Castillo, C., A. Cuerva-Tejero, and O. Lopez-Garcia, A review on the recent history of wind power ramp forecasting. Renewable and Sustainable Energy Reviews, 2015. 52: p. 1148-1157.

[3] Lee, J., et al., Wind Power Prediction Using Ensemble Learning-Based Models. IEEE Access, 2020. 8: p. 61517-61527.

[4] Rahman, S. and B.H. Chowdhury, Simulation of photovoltaic power systems and their performance prediction. IEEE Transactions on Energy Conversion, 1988. 3(3): p. 440-446.

[5] Moharil, R.M. and P.S. Kulkarni, Reliability analysis of solar photovoltaic system using hourly mean solar radiation data. Solar Energy, 2010. 84(4): p. 691-702.

[6] Nikolova, S., A. Causevski, and A. Al-Salaymeh, Optimal operation of conventional power plants in power system with integrated renewable energy sources. Energy Conversion and Management, 2013. 65: p. 697-703.

[7] Yang, X., et al., An Operation Benefit Analysis and Decision Model of Thermal Power Enterprises in China against the Background of Large-Scale New Energy Consumption. Sustainability, 2020. 12(11).

[8] Yang, Y., et al., Interval Optimization-Based Unit Commitment for Deep Peak Regulation of Thermal Units. Energies, 2019. 12(5).

[9] Yang, B., et al., Unit Commitment Comprehensive Optimal Model Considering the Cost of Wind Power Curtailment and Deep Peak Regulation of Thermal Unit. IEEE Access, 2020. 8: p. 71318-71325.

[10] Dong, Y., et al., Coal power flexibility, energy efficiency and pollutant emissions implications in China: A plant-level analysis based on case units. Resources, Conservation and Recycling, 2018. 134: p. 184-195.

[11] Kopiske, J., S. Spieker, and G. Tsatsaronis, Value of power plant flexibility in power systems with high shares of variable renewables: A scenario outlook for Germany 2035. Energy, 2017. 137: p. 823-833.

[12] Mikkola, J. and P.D. Lund, Modeling flexibility and optimal use of existing power plants with large-scale variable renewable power schemes. Energy, 2016. 112: p. 364-375.

[13] Kubik, M.L., P.J. Coker, and J.F. Barlow, Increasing thermal plant flexibility in a high renewables power system. Applied Energy, 2015. 154: p. 102-111.

[14] Brouwer, A.S., et al., Operational flexibility and economics of power plants in future low-carbon power systems. Applied Energy, 2015. 156: p. 107-128.