Integrated Energy Production Unit: An Innovative Concept and Design for Energy Transition Toward Low-carbon Development

Xiaoxin Zhou, *Life Fellow*, *IEEE*, Qiang Zhao, Yuqiong Zhang, and Li Sun, *Member*, *IEEE*

***Abstract*—To achieve the goals of emission peak and carbon neutrality, significant effort is invested to accelerate the energy transition, with a focus on the development and utilization of renewable energy, as well as the upgrading of conventional units. Within this context, this paper proposes an innovative concept, known as the integrated energy production unit (IEPU), providing a variety of energy products and flexible adjustment functions for power systems with high penetration of non-hydro renewable energy. In the IEPU framework, a photovoltaic (PV) power plant is installed to produce electricity; CO_2 capture technology is applied to the existing coal-fired power plant with biomass co-combustion. The generated CO_2 is used to synthesize methane or methanol with hydrogen through electrolysis. First, the operational principle and advantages of this concept are illustrated. Then, a simplified model is built to provide an optimal configuration scheme of equipment capacity. Finally, the potential contribution of IEPU to the operational flexibility of the power system is also analyzed.**

***Index Terms*—CO_2 capture, flexibility, hydrogen production from renewables, integrated energy production unit, methane/methanol.**

I. INTRODUCTION

To cope with the threat of climate change, China announced the targets of CO_2 emission peak and carbon neutrality to be realized before 2030 and 2060 respectively [1]. The 14th Five-Year Plan (FYP) of China further proposed that carbon dioxide emissions per unit of GDP should decrease by 18% during the 14th FYP period and the proportion of non-fossil energy in total energy consumption will be increased to about 20% by 2025 [2]. The goals of building "a clean, low-carbon, safe and efficient energy system" [2] and "a new power system dominated by non-hydro renewable energy" [3] will accelerate the energy transition of China.

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X. X. Zhou (corresponding author, e-mail: xxzhou123@163.com), Q. Zhao and Y. Q. Zhang are with China Electric Power Research Institute, Beijing 100192, China.

L. Sun is with the Key Lab of Energy Thermal Conversion and Control of the Ministry of Education, School of Energy and Environment, Southeast University, Nanjing 210089, China.

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From the perspective of power supply, there are two major aspects to achieving these goals: 1) the substantial increase of renewable energy generation in the energy profile; 2) the upgrading of conventional coal-fired generation units, to provide values on compensating renewable generation and emission reduction. For the first aspect, the volatility, intermittence, and uncertainty of wind and photovoltaic generation are the primary obstacles in increasing the renewable generation proportion, which could be tackled by integrating other technologies such as power to hydrogen (P2H). For the second, a large number of coal-fired power plants are still in service in China, which require the clean and green transition of economic and efficient solutions. Responding to these demands, the integrated energy production unit (IEPU) is proposed as a practical solution that will kill two birds with one stone. The IEPU introduces renewable generation, such as PV and biomass co-combustion, carbon dioxide capture, and P2H, specifically the hydrogen production device through water electrolysis and methane/methanol synthesis, to the legacy coal-fired power plants.

The proposal of the IEPU framework was partly inspired by the vision of Liquid sunshine, which combines the sun's energy with carbon dioxide and water to produce green liquid fuels [4], [5]. Many fundamental studies have been conducted by Prof. Li Can's team to promote the technology development and application [6]–[8]. Also, a demonstration project started operation in Lanzhou, China, verifying the engineering feasibility of combining solar PV to generate electricity, electrolyzer to produce hydrogen; and CO_2 hydrogenation to produce methanol [9].

A lot of studies have been carried out on the non-hydro renewable energy generation, carbon dioxide capture and P2H, especially on modeling of P2H, CO_2 capture and methane/methanol synthesis [10]–[14]. In terms of integrated energy, many researches are performed on the optimization of dispatching strategy [15]–[23] and equipment capacity [24]–[28], while most of them are based on limited equipment. The feasibility and value of IEPU to the future energy system require further study.

This paper illustrates the following contents: 1) the structure and working principle of the IEPU; 2) a simplified model to provide an optimized capacity planning scheme; 3) the optimal operation to demonstrate the flexibility value provided by the IEPU to grids, compared with conventional coal-fired generation units; 4) some discussions to clarify several issues on engineering practice which are not mentioned in other sections.

II. Methodology

The integrated energy production unit (IEPU), as shown in Fig. 1, combines PV equipment, a coal-fired power plant which can be combined with biomass co-combustion, CO_2 capture devices, electrolytic hydrogen production devices, and a methane/methanol synthesis facility into a single system. This design is anticipated to promote the development and utilization of renewable energy as well as the upgrading of conventional power plants. It should be noted that Fig. 1 just shows a typical framework or case of the IEPU. Actually, the concept of IEPU can be extended and realized with different structures. More details will be given in Section IV.

A. Working Principle

During the daytime, the photovoltaic generation unit in the IEPU is used to power hydrogen production and customer loads, which are complemented by the coal-fired generation unit with biomass co-combustion. At night, the coal-fired generation unit becomes the power source to ensure the continuous and stable operation of the electrolytic hydrogen production system. The produced hydrogen and the CO_2 captured from the coal-fired power plant are synthesized to produce methane/methanol. The gas storage devices are also required to provide smooth gas flow and pressure, enabling the coordinated work of all components.

Overall, various types of energy are utilized comprehensively in the IEPU, generating greener electric power for loads inside the serving area, as well as producing transportable and storable chemical products to replace fossil fuel for outside the serving area. From the perspective of the grid, the hydrogen production system is a dispatchable load and energy storage unit, and thus could serve as a flexible resource. In terms of energy production, CO_2 capture contributes to the emission reduction and provides material for methane/methanol synthesis.

B. System Model

A simplified model is built to make a preliminary analysis on the operation characteristics of the IEPU. In order to describe the coupling relationships between the main processes and output of the IEPU, the model includes the input-output equations of photovoltaic power generation device, coal-fired generation unit with carbon capture function, water-electrolysis hydrogen production equipment, methane/methanol synthesis equipment, and the gas storage devices of hydrogen and CO_2. For the sake of simplicity and considering the high proportion and total capacity of the coal-fired generation in China, the biomass co-combustion is neglected in this case.

1) Photovoltaic Power Generation Equipment

The theoretically maximum power output at the time of t of the PV equipment $E_{\mathrm{PV},t}$ (kW), is described as:

$$E_{\mathrm{PV},t} = \frac{GHI_t}{GHI_{\mathrm{r}}} CAP_{\mathrm{PV}} \tag{1}$$

where GHI_t (kW/m^2) is the global horizontal irradiance, representing the available solar energy irradiance per unit area

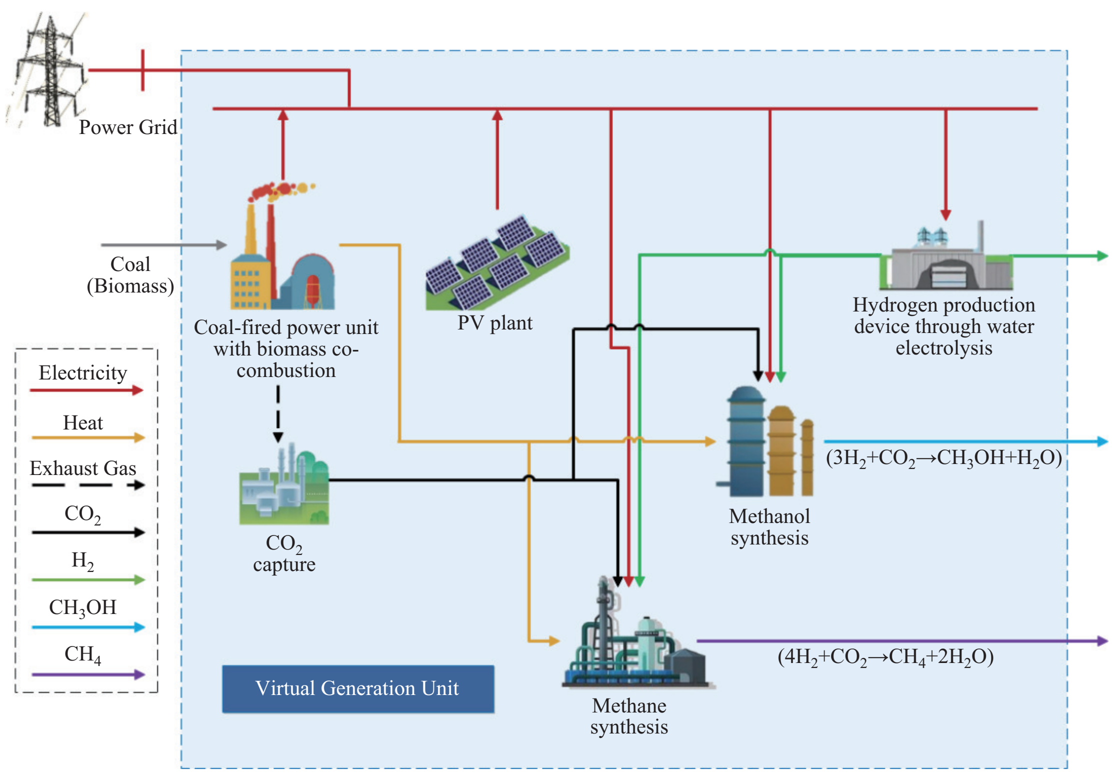

Fig. 1. Structure of integrated energy production unit (IEPU). (Note: As originally published there is an error in this document. A corrected replacement file was provided by the authors to fix a typographical error in Fig. 1, which does not otherwise affect the research conclusions.)

of photovoltaic panel at t time; GHI_{r} is denoted as the GHI under rated condition; CAP_{PV} is the rated power of the PV equipment. The actual output power of the PV panel $E_{\mathrm{PV},t}$ (kW) cannot exceed $E_{\mathrm{PV},t}$:

$$0 \leq E_{\mathrm{PV},t} \leq E_{\mathrm{PV},t} \tag{2}$$

2) Carbon Capture in Coal-fired Generation Unit

The CO_2 emission of the coal-fired generation unit at the time of t is $M_{\mathrm{CO_2\_CGU},t}$ (ton), related to its output power $E_{\mathrm{CGU,t}}$(kW), and emission intensity $e_{\mathrm{CGU},t}$ (kg/kWh), as shown in (3):

$$M_{\mathrm{CO_2\_CGU},t} = e_{\mathrm{CGU}} \times E_{\mathrm{CGU},t} \times \Delta t \times 0.001 \tag{3}$$

where Δt equals to 1 hour; e_{CGU}, depending on the type of coal, is set around 0.9 kg/kWh.

The carbon dioxide actually captured $M_{\mathrm{CO_2\_CCS},t}$ (ton) is affected by the capture efficiency η_{CCS} (%), and capture ratio λ_{CCS} (%):

$$M_{\mathrm{CO_2\_CCS},t} = \eta_{\mathrm{CCS}} \times \lambda_{\mathrm{CCS}} \times M_{\mathrm{CO_2\_CCS},t} \tag{4}$$

where η_{CCS} and λ_{CCS} are both between 0 and 1. η_{CCS} can be set to 80%. λ_{CCS} is determined by the demand of CO_2.

3) Gas Storage and Mass Balance

For the purpose of simplicity, it is considered that the methane/methanol synthesis is governed by the reactions described as:

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O \tag{5}$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \tag{6}$$

which decide the production of methane/methanol:

$$M_{\mathrm{CH_4},t} = \alpha M_{\mathrm{CO_2\_M1},t} \tag{7}$$

$$M_{\mathrm{CH_3OH},t} = \beta M_{\mathrm{CO_2\_M2},t} \tag{8}$$

where $\alpha = 16/44$ and $\beta = 32/44$ are respectively the mass ratio coefficient of methane/methanol to CO_2. $M_{\mathrm{CO_2\_M1},t}$ and $M_{\mathrm{CO_2\_M2},t}$ stand for the mass of CO_2 used for methane and methanol synthesis respectively.

The hydrogen and CO_2 storage devices are necessary to address the problem of imbalance between the production and demand of material. Equations (9) and (10) describe such processes:

$$M_{\mathrm{H_2\_st},t} = M_{\mathrm{H_2\_st},t-1} + M_{\mathrm{H_2\_in},t-1} - M_{\mathrm{H_2\_out},t-1} \tag{9}$$

$$M_{\mathrm{CO_2\_st},t} = M_{\mathrm{CO_2\_st},t-1} + M_{\mathrm{CO_2\_in},t-1} - M_{\mathrm{CO_2\_out},t-1} \tag{10}$$

where $M_{\mathrm{H_2\_st},t}$ (ton) and $M_{\mathrm{H_2\_st},t-1}$ (ton) represent the stored H_2 in the tank at the time of t and t-1, respectively. $M_{\mathrm{H_2\_in},t-1}$ (ton) and $M_{\mathrm{H_2\_out},t-1}$ (ton) are the amount of inlet and outlet hydrogen at the time of t-1. The meanings of the symbols in (11) are similar.

The mass balance of hydrogen and CO_2 are expressed as:

$$M_{\mathrm{H_2\_EL},t} + M_{\mathrm{H_2\_out},t} = M_{\mathrm{H_2\_M},t} + M_{\mathrm{H_2\_in},t} \tag{11}$$

$$M_{\mathrm{CO_2\_CCS},t} + M_{\mathrm{CO_2\_out},t} = M_{\mathrm{CO_2\_M},t} + M_{\mathrm{CO_2\_in},t} \tag{12}$$

where $M_{\mathrm{H_2\_EL},t}$ (ton) is the hydrogen produced by electrolyzer at the time of t; $M_{\mathrm{H_2\_M},t}$ (ton) and $\mathrm{M}_{\mathrm{CO_2\_M},t}$ (ton) respectively stands for the hydrogen and CO_2 used for methane/methanol synthesis.

4) Power Balance

Inside the system, the PV equipment and coal-fired generation units collectively provide electricity power. The process of carbon capture, water-electrolysis hydrogen production, methane/methanol synthesis, as well as the load demand from dispatching order ($E_{\mathrm{d},t}$) are all load demands. Thus, the power balance is described as:

$$E_{\mathrm{PV},t} + E_{\mathrm{CGU},t} = E_{\mathrm{CCS},t} + E_{\mathrm{EL},t} + E_{\mathrm{M},t} + E_{\mathrm{d},t} \tag{13}$$

where $E_{\mathrm{CCS},t}$, $E_{\mathrm{EL},t}$, $E_{\mathrm{M},t}$ are denoted as the power demand of CO_2 capture, electrolyzer and methane/methanol synthesis, respectively.

C. Primary Constrains

Incorporating engineering experiences, the primary constraints are set as follows. First, the output of the coal-fired generation unit is limited to a certain range, which is set to 30%–100% of the unit capacity (assuming that the ability of deep peak shaving of coal-fired generation unit is improved). Secondly, the risk of electrolyte freezing requires the P2H production system to operate with an uninterrupted power above 30% of rated. Thirdly, the outputs of all equipment, except for PV generator, cannot exceed the rated powers. Finally, the amount of stored gas is limited according to the capacity of its storage devices.

D. Definition of Optimization Objective

The optimization objective is to realize the economic benefits through the optimal configuration of the IEPU equipment capacity. This includes reducing costs and increasing revenue. Hence, the objective function is:

$$obj = B_{\mathrm{tot}} - C_{\mathrm{tot}} \tag{14}$$

which considers the cost and benefit of the whole system. The cost C_{tot} includes investment costs (denoted as C_{inv}), O&M costs (denoted as C_{OM}) of all the devices and the fuel costs (denoted as C_{fuel}) of the coal-fired generation unit. The benefit, B_{tot}, contains the incomes from the sale of products (electricity and methane/methanol included) and the subsidy for carbon emission reduction. Then, the objective function is calculated as:

$$P_{\mathrm{tot}} = \sum_i B_{\mathrm{tot},i} - \sum_j \left(C_{\mathrm{inv},j} + C_{\mathrm{OM},j} + C_{\mathrm{fuel},j}\right) \tag{15}$$

where the subscript i indicates the order numbers of products; the subscript j indicates the order numbers of devices. $C_{\mathrm{inv},j}$ and $C_{\mathrm{OM},j}$ are related to unit investment cost and OM cost with the capacity of the device j. The discount rate is also considered and set as 10%.

With the capacities of all the devices in the IEPU are optimized, an operational optimization can be executed to make further analysis on its output characteristics from the view of flexibility.

III. Simulation and Optimization

Based on the system model and defined optimization objective, a typical application scenario of the IEPU is established for simulation. The IEPU equipment capacities are first configured based on the above-mentioned optimization objective. The adjustment potential is then calculated based on a selected typical load curve with distinctive peak and valley.

A. Capacity Configuration

It is assumed that the IEPU is built by reusing and extending the service time of a decommissioned 300 MW coal-fired generation unit; therefore, the investment cost is negligible. Considering the engineering feasibility and scale limitation, the maximum storage of CO_2 and H_2 are both set as 40,000 Nm^3; the annual operating time of the coal-fired generation unit is limited below 4500 h. In the simulated scenario, the given solar resource profile and load curve are introduced as the key boundaries for power supply-demand balance. An optimization problem is solved aiming to maximize the objective function in (14), subjected to all the constraint conditions described in Section II. For the sake of simplicity, the optimizations are based on the typical weekly curve of $E_{\mathrm{d},t}$ and $E_{\mathrm{PV},t}$ of each season, with a one-hour time step.

1) Parameters

Here we take the methanol (MeOH) production for simulation analysis. Some main parameters used in the model are shown in Table I. Please note that most of the parameter settings consider the cost reduction brought by future technology advancement.

2) Results

The optimization problem is formulated by mixed integer linear programming (MILP). The CPLEX solver in the MATLAB environment is adopted in modeling and simulation. The whole solving process requires around 40 seconds of CPU time on an Intel(R) Core(TM) i7-9700 CPU with a memory size of 8.00 GB. More than 14,000 continuous variables, 1300 0–1 variables, and 35,000 constraints are included.

The optimal capacities of the units is shown as Table II. With various equipment working coordinately, both the coal-fired generation unit and PV unit exceed their usual annual operation times, when compared to the most typical applications at present. About 167 thousand tons of CO_2, approximately 20.8% of total emission, are captured annually in the coal-fired generation unit, consuming about 16.2 million kWh of electricity. The optimized capacity of the electrolyzer is 164 MW, producing 0.252 billion Nm^3 of hydrogen and consuming 1.06 billion kWh of electricity within one year. The PV unit with a total capacity of 226 MW generates about 0.435 billion kWh of power, equivalent to 41 percent of the electricity demand of the electrolyzer. About 120 thousand tons of methanol are synthesized accordingly.

Figure 2 shows the production or consumption of electric power by each piece of equipment of the IEPU on the second day of a typical week in summer. The bars with positive value suggest the generation of electric power, while the negative values represent consumption. The curve stands for the net power output of the IEPU, denoted as $P_{\mathrm{n},t}$, which is calculated by $E_{\mathrm{PV},t} + E_{\mathrm{CGU},t} - E_{\mathrm{CCS},t} - E_{\mathrm{EL},t} - E_{\mathrm{M},t}$. From (13),

TABLE I
MAIN PARAMETERS FOR CAPACITY PLANNING

Equipment	Parameter	Quantity
Coal-fired generation unit	Annual OM cost (¥/a)	100,000,000
	Fuel cost (¥/tce)	450
	Investment cost of carbon capture equipment (¥)	100,000,000
	Coal consumption (gce/kWh)	310
Electrolyzer	Investment cost (¥/kW)	2000
	Annual OM cost (¥/kW)	Investment cost ×4%
	Life (year)	10
	Power consumption (kWh/Nm^3)	4.2
PV equipment	Investment cost (¥/kW)	1500
	Annual OM cost (¥/kW)	50
Methanol synthesis plant	Investment cost (¥/(tMeOH/yr))	4000 [29]
	Annual OM cost (¥/(tMeOH/yr))	200 [29]
	Methanol price (¥/tMeOH)	2800

*The exchange rate of USD to RMB can be set between 6 and 7.

TABLE II
RESULTS OF CAPACITY PLANNING

Equipment	Parameter	Quantity
Coal-fired generation unit	Annual operating time (h)	4500
	Carbon dioxide captured (t)	167,450
Electrolyzer	Capacity (MW)	164
	Production of the hydrogen (Billion Nm^3)	0.252
PV equipment	Capacity (MW)	226
	Annual operating time (h)	1924
Methanol synthesis plant	Capacity (tMeOH/a)	119,790

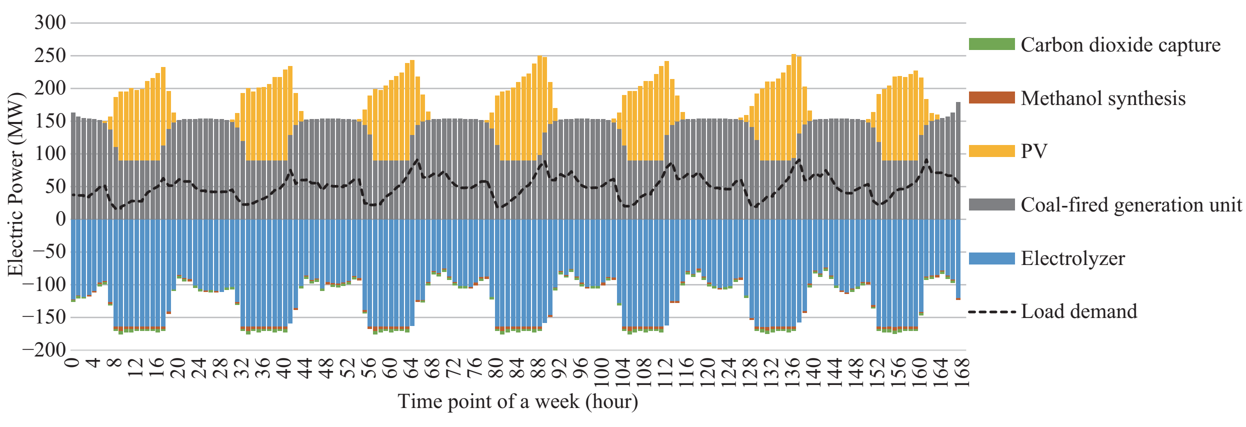

Fig. 2. Electric power dispatch for a typical week in summer.

this net output is equal to $E_{\mathrm{d},t}$, which is actually the load demand from the dispatching center of the grid, if the IEPU is regarded as the virtual generation unit. Fig. 2 shows that the load during daytime is powered by the PV and coal-fired generation unit together, since PV is cost-competitive and does not emit carbon. The electrolyzer acts as the most important load continuously working at around full capacity. This result suggests that under the parameters of Table I, it has a remarkable economic benefit to produce methanol from CO_2 and H_2 with IEPU.

B. Analysis of Flexibility for Power System Operation

One of the most significant evaluation indexes on flexibility is the maximum range of adjustment, i.e., the difference between the upper and lower limits of $P_{\mathrm{n},t}$. The equipment capacity provides constraints for its actual output power, which is the hourly variable, since the time step is 1 h. For the coal-fired generation unit alone, $P_{\mathrm{n},t}$, which equals to $E_{\mathrm{CGU},t}$, changes from 30% to 100% of its rated capacity, so the range is 70% of the unit capacity. The IEPU, however, contains additional adjustable power loads and generators.

The upper limit of $P_{\mathrm{n},t}$, $P_{\mathrm{n,max}}$ is calculated as (16):

$$P_{\mathrm{n,max}} = E_{\mathrm{CGU,r}} + E_{\mathrm{PV,max}} - E_{\mathrm{EL,min}} \tag{16}$$

where $E_{\mathrm{CGU,r}}$ is the rated capacity of the coal-fired generation unit, which is equal to 300 MW in this paper; $E_{\mathrm{PV,max}}$ stands for the maximum output of PV unit, which is around its rated capacity; $E_{\mathrm{EL,min}}$ is the minimum consumption of the electrolyzer.

The lower limit of $P_{\mathrm{n},t}$, $P_{\mathrm{n,min}}$ is calculated as (17):

$$P_{\mathrm{n,min}} = E_{\mathrm{CGU,min}} - E_{\mathrm{EL,tp}} - E_{\mathrm{CCS,tp}} - E_{\mathrm{M,tp}} \tag{17}$$

where $E_{\mathrm{CGU,min}}$ represents the minimum output of the coal-fired generation unit, which is equal to 30% of its rated capacity; $E_{\mathrm{EL,tp}}$ is the maximum load of the electrolyzer, with the subscript, tp, representing the moment of peak. The CO_2 capture and methanol synthesis consumes very little electricity compared with that of the electrolyzer. Thus, $E_{\mathrm{CCS,tp}}$ and $E_{\mathrm{M,tp}}$ are almost negligible.

Based on the results of the capacity configuration in Table II, $P_{\mathrm{n,max}}$ is about 477 MW by (16) and $P_{\mathrm{n,min}}$ equals to -74 MW by (17). Therefore, the maximum adjustment range of the IEPU is 551 MW, which is about 183% of the rated capacity of the conventional coal-fired generation unit. Accordingly, the adjustment range is increased by 2.6 times.

An operational optimization is performed for a typical day, based on the set units capacity shown in Table II. The daily load demand curve is set as $P_{\mathrm{n,max}}$ at the moment of $E_{\mathrm{PV,max}}$ and $P_{\mathrm{n,min}}$ at a specific moment with $E_{\mathrm{PV},t} = 0$. Fig. 3 shows the simulation results. The curve with the triangle markers shows the theoretically maximum output of the IEPU, which is affected by the PV unit output at the time. The curve with square markers shows the theoretically minimum output of IEPU, which is equal to $P_{\mathrm{n,min}}$. It is demonstrated that the IEPU, as a virtual unit, can provide remarkably higher flexibility for the grid than the conventional coal-fired generation unit.

IV. Discussions

In this section, we provide some further discussions on the value and prospects of the IEPU which are not covered in the above sections. The purpose is to provide a broader perspective and context beyond the scope of this paper.

The proposal for the IEPU is anticipated to provide a solution for the retirement and transformation of a large number of existing thermal power units in China. The integration of a coal-fired power generation unit and electrolyzer is an effective way to improve the flexibility of the power grid, as well as to compensate for the uncertainties of renewable energy and ensure its full accommodation. The structure in Fig. 1, to some extent, shows one of the various forms of the IEPU. It may be more practical and acceptable in the current stage of development in China due to a large number of existing coal-fired generation units. The electricity consumed by hydrogen production in the IEPU system is partly from photovoltaic power generation and the rest is from the thermal power plant. Accordingly, the hydrogen is not purely produced from a traditional coal-fired power plant. To deal with the problem of CO_2 emission from fossil fuel, the carbon dioxide capture and co-combustion of biomass are integrated into the unit. Therefore, from the perspective of the whole system, if the scale of these two technologies could cover or surpass the CO_2 emission during hydrogen production, the whole process results in zero carbon or even negative carbon emission.

In the later stage of energy transformation with higher penetration of renewable energy, the framework of the IEPU

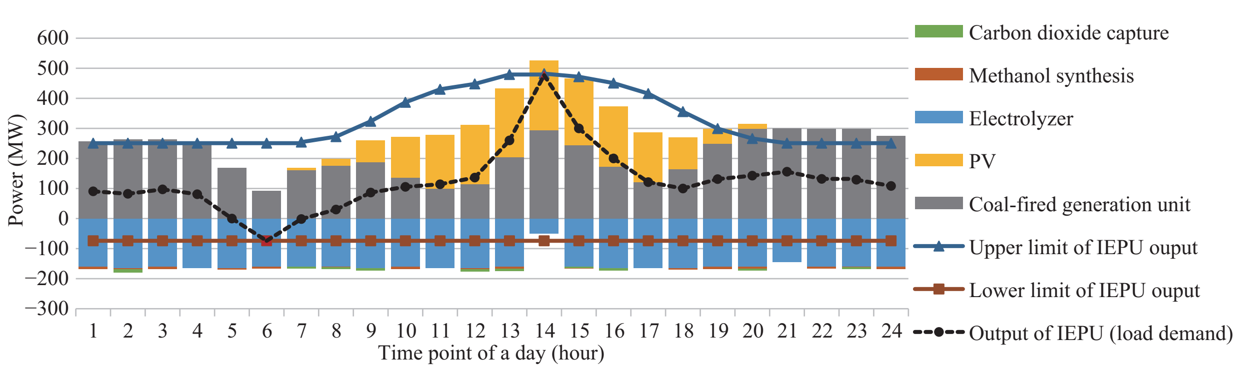

Fig. 3. Test on flexibility of IEPU.

can be expanded with: 1) producing hydrogen by larger quantities of wind, solar or hydro power; 2) the utilization of the direct air capture (DAC) of CO_2; 3) a wider range of products, such as methane, methanol or ammonia which requires no CO_2; 4) co-combustion of biomass with a higher proportion in the coal-fired generation power plant.

The IEPU idea is partly inspired by some existing concepts, such as the integrated energy system or energy hub, but which has a different connotation and intention. First, the energy hub usually focuses on the energy integration in the energy consumption side, including different forms of energy, including electricity, cold and heat. The IEPU, however, concentrates on the energy supply side, aiming to utilize the renewable energy and carbon emission reduction of the thermal power units. Secondly, the energy hub pays more attention to the internal balance and autonomous operation of the system while the IPEU emphasizes its interaction with the power grid and contribution to flexibility, especially on a long-time scale. Another concept, the integrated energy consumption unit (IECU), which is currently being studied by the authors, is more similar to the energy hub since it faces the demand side (mixed with minor distributed generation). Both IEPU and IECU, combining with digital and intelligent technology, may become the basic elements of the smart energy and power system in the future.

In terms of engineering practice, a large number of issues need to be clarified, including but not limited to the following three aspects:

1) The feasibility study of the IEPU should be carried out with further and detailed economic analyses based on specific projects. We made a preliminary economic evaluation on an IPEU case including a 140 MW electrolyzer and 180 MW PV equipment. From the parameters in Table I, the results suggest that the dynamic payback period of investment is about 15 years and the internal rate of return (IRR) is approximately 13%. This calculation may be somewhat optimistic since the model is idealistic and many details of the actual process are ignored. Nevertheless, the economic feasibility is expected to be improved, with the continuous technical progress and cost decrease of renewable power generation and electrolyzer, as well as the policy market and mechanism support for green energy.

2) Considering the components integrated in the IEPU, the potential application scenarios are primarily located in suburban areas in the northwest and northern China or Inner Mongolia. The preliminary principles for selecting the locations include:

- It is convenient to arrive at existing thermal power units;
- There are abundant renewable energy resources among which PV and/or wind power can be located in the distance as a virtual member of the IEPU;
- Enough water resources are available;
- The space is sufficient for storage and installation of equipment;
- It is convenient for the transportation of methanol/ methane products.

3) Since hydrogen in the IEPU is only used as an intermediate product, the electrolyzer and methane/methanol synthesis plant are installed near to each other, avoiding the long-distance transportation of hydrogen. Storage devices with appropriate capacity, however, are necessary to ensure the stability of the chemical reaction in methane/methanol synthesis, and high-pressure gaseous storage is preferred taking the cost, land demand, and technology maturity into account. On the product side, methanol, as a type of liquid fuel, can be transported by tankers with mature transportation specifications; Methane, as the major component of natural gas, can be directly sent to the natural gas pipeline.

V. Conclusion

This paper has proposed the concept of the integrated energy production unit (IEPU), combining the conventional coal-fired generation unit with biomass co-combustion and CO_2 capture, PV, hydrogen production through water electrolysis and methanol/methane. With the advantage in supplying various green/clean and facilitated transport energy products and providing a wider range of system flexibility adjustments, the IEPU is expected to be an economic and efficient solution for the low-carbon/zero-carbon transformation of the coal-fired power plant and to support the safe and stable operation of power systems with high penetration of non-hydro renewable energy. Further studies are expected on a more detailed feasibility of the IEPU application in power systems, including recent available and further requirement of technologies, benefits, economic analysis, and etc.

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Xiaoxin Zhou (F'96–LF'10) graduated from the Electrical Engineering Department, Tsinghua University, Beijing, China, in 1965. He is currently a Member of the Chinese Academy of Sciences and an International Member of the US National Academy of Engineering (NAE). He is a professor-level senior engineer and doctoral tutor, Honorary President of China Electric Power Research Institute, Standing Council Member of the Chinese Society for Electrical Engineering and Chairman of its Academic Work Committee, and Standing Council Member of the China Electrotechnical Society. In 2008, he received the Nari Hingorani FACTS Award from the IEEE Power and Energy Society. He was awarded with the National Science and Technology Progress Award, and the Ho Leung Ho Lee Science and Technology Progress Award. His research interests include power systems, real-time simulation technology and renewable energy generation.

Qiang Zhao received the B.S. degree from Northeast Electric Power University in 2001 and the M.S. degree from Harbin Institute of Technology in 2004. From 2004 to 2011, he was an electrical engineer with the Power System Department of China Electric Power Research Institute (CEPRI). He is currently a professor-level senior engineer with the Technology and Strategy Research Center of CEPRI. His research interests include power system stability analysis, energy strategy, application of energy storage and hydrogen in power system.

Yuqiong Zhang received the B.S. degree from North China Electric Power University in 2010 and the Ph.D. degree from Tsinghua University in 2016. She is currently a senior engineer with China Electric Power Research Institute. Her current research interests include integrated energy systems, energy strategy and planning, and the application of energy storage in power systems.

Li Sun (M'17) received the B.S degree from Southeast University in 2012 and the Ph.D. degree from the Department of Thermal Engineering, Tsinghua University in 2017. He is currently an Associate Professor with the School of Energy and Environment, Southeast University. Dr. Sun was a Guest Associate Editor for the IFAC Journal on Control Engineering Practice and Associate Editor of American Control Conference.