IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received April 11, 2021, accepted May 6, 2021, date of publication May 17, 2021, date of current version May 27, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3081011

Energy Storage Sizing Optimization for Large-Scale PV Power Plant

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ABSTRACT The optimal configuration of energy storage capacity is an important issue for large scale solar systems. a strategy for optimal allocation of energy storage is proposed in this paper. First various scenarios and their value of energy storage in PV applications are discussed. Then a double-layer decision architecture is proposed in this article. Net present value, investment payback period, internal rate of return are taken as the outer objective function, energy storage capacity is the optimal variables. The investment cost of energy storage system is taken as the inner objective function, the charge and discharge strategy of the energy storage system and augmentation are the optimal variables. Finally, the effectiveness and feasibility of the proposed model and method are verified through case simulations. The results show that the comprehensive evaluation index can be aimed at the concerns of energy storage investors, comprehensively evaluate the feasibility of the energy storage project, and obtain the corresponding energy storage scale when the comprehensive evaluation index is the highest.

INDEX TERMS Levelized cost of energy (LCOE), LFP, PV plus storage, benefits/cost, augmentation plan, inverter loading ratio (ILR), AC-coupled, DC-coupled.

I. INTRODUCTION

Solar energy resources are abundant and widely distributed throughout the world, and Photovoltaic (PV) power generation technology is the most promising technology of renewable energy power generation technology. PV is a technology that directly converts solar energy into electricity by using the photovoltaic effect of semiconductor interface. It is safe, clean and efficient [1], [2]. By 2030, the annual installed capacity of solar photovoltaic new installations will be nearly 270 GW per year, and by 2050, it will need to increase up to 372 GW per year [3]. Asia is expected to drive the trend of solar photovoltaic power generation and become a world leader in solar photovoltaic energy. In terms of total installed capacity, Asia (mainly China) will continue to dominate solar photovoltaic power generation, and its share will exceed 50% by 2050, followed by North America (20%) and Europe (10%). Increasing investment in solar photovoltaic energy is critical to accelerating the development of future energy. Globally, this means that from now until 2050, solar photovoltaic investment will be up to \$ 1920 billion / year [3].

There are also many challenges in the development of large-scale PV system. The challenges are: 1) Land issues. The hours of PV power generation are relatively low, and the floor area is large. Sufficient land area is required to build PV plants. 2) Grid transmission problems. The location of the PV power station needs to be close to the grid substation, and the transmission lines with sufficient capacity are connected to the grid; Large-scale PV power generation requires load matching, either close to the load center, or sending PV power to the load center via long-distance transmission [4], [5].

While Energy storage systems are suppressing PV power fluctuations and improving grid connection friendly. Large scale PV power plant plus storage has become an important configuration for the development of global energy.

In the United States, more than 2GW/6GWh is expected in 2021 alone. Solar plus storage projects follow the participation rules of their generating assets. All six ISOs are reviewing and implementing new frameworks for solar plus storage market participation. The growth rate of the solar plus storage market will reach 15% by 2023. The application of energy storage in PV power plants will be the main application form of energy storage application scenarios. By 2023, about 55% of energy storage will be used in PV power plants. In addition,

The associate editor coordinating the review of this manuscript and approving it for publication was Lorenzo Ciani.

with the decline in battery prices and the sharp decline in the price of PV BOS equipment, solar plus storage applications have become more widespread [6].

The Chinese energy storage market pivoted from transmission and distribution level services to renewable integration in 2020. totally 16 renewable-plus-storage projects are announced in first half year, spread across 12 provinces. As of the end of 2019, the cumulative installed capacity of the energy storage projects (including molten salt heat storage projects) that have been put into operation in China to support PV power generation was 800.1MW, of which the cumulative installed capacity of energy storage projects built with centralized PV power plants It is 625.1MW. The installed capacity of the newly commissioned optical storage project in 2020 was 320.5MW, a year-on-year increase of 16.2%.

Reasonable allocation of energy storage capacity is an important prerequisite to ensure the economic efficiency of the PV power generation system and increase the investment enthusiasm of power generation companies. The problem of energy storage capacity allocation has become a hot topic.

Conventional energy storage capacity allocation methods mainly aim at the lowest energy storage cost [7], the greatest benefit [8]–[11], the highest return on investment [12], and the smallest capacity [13], [14] to establish a mathematical model for energy storage capacity optimization.

The literature [8] emphasized the configuration and structure of energy storage in PV power plants, and compared the efficiency, but did not study in-depth how to optimize the capacity. The literature [9]–[11] mainly studies the optimal configuration of energy storage capacity for residential energy storage, which is not suitable for large-scale energy storage capacity configuration. Literature [15] established a multi-objective optimization model with the highest energy efficiency, the lowest energy storage system investment and operating costs, and the lowest environmental pollution cost from the perspectives of energy efficiency, economy, and environment. Reference [16] established an energy storage optimization objective function that considers economy, peak clipping and valley filling, and improved voltage quality. Reference [17] has established a multi-objective optimal configuration model from the technical perspectives of peak-shaving and valley-filling capacity, voltage quality and power regulation capacity of energy storage applications.

Most of the above studies focused on energy storage and did not fully consider the overall modeling of PV and energy storage. With the increasing number of PV energy storage projects, the overall revenue of PV + energy storage, the overall modeling and configuration are closely watched.

Based on the existing research results, from the perspective of project investors, a double-layer decision architecture is proposed in this article. Net present value (NPV), investment payback period, investment return rate (IRR) are taken as the outer objective function, energy storage capacity is the optimal variables. The investment cost of energy storage system is taken as the inner objective function, the charge and discharge strategy of the energy storage system and augmentation are the optimal variables.

TABLE 1. Different application scenario for PV plus storage.

Application scenario	Description
Frequency Regulation	Corrects over and under frequency
Ramp rate control	Mitigates ramping at generation source
PV output smoothing	Maintains approximate solar curve
PV Capacity Firming	Creates firm committed load shape
PV Energy Shifting	Shifts solar to evening hours with or w/o commit

The innovations of this article are:

1) Overall modeling of photovoltaic and energy storage. The energy storage model fully considers the output characteristics of PV and uses PVsyst to establish PV models and establish energy storage scheduling control strategies. On the one hand, it reduces the planned capacity of energy storage, avoids being too radical, and improves economy. On the other hand, a reasonable energy storage scheduling strategy can be formulated to improve the life and utilization of energy storage batteries.

2) Considering the battery attenuation characteristics, especially the Augmentation model is established. Through calculation and analysis, the augmentation strategy can be quickly formulated, thereby reducing the total investment of the system.

3)Use a double-layer optimization model, where the inner optimization has the lowest initial investment cost. Outer layer optimization Multi-index optimization. The project has the highest return. And use multiple indicators to evaluate to avoid the one-sidedness of a single indicator.

The paper is structured as follows. Section 2 discusses the main applications of energy storage. Section 3 discusses metrics and methods to evaluate technical and economic performance. Section 4 presents a case study evaluating the energy storage sizing based on double layer decision architecture introduced in Section 3. The conclusions are summarized in Section 5.

II. ENERGY STORAGE APPLICATION

Energy storage is used in PV power plants, and its functions include 1) frequency regulation 2) power ramp rate control 3) PV output power smoothing 4) PV capacity firming 5) and energy shifting (Figure 1). An energy storage system can operate in parallel with a PV power plant in different operation modes, depending on the desired functionality. Five typical applications and operation strategies for utility scale PV plants are described as Table 1 shown. They are defined according to different time scale from minutes level to hours level (Figure 1).

A. FREQUENCY REGULATION

Energy storage frequency regulation includes the primary frequency regulation and the secondary frequency

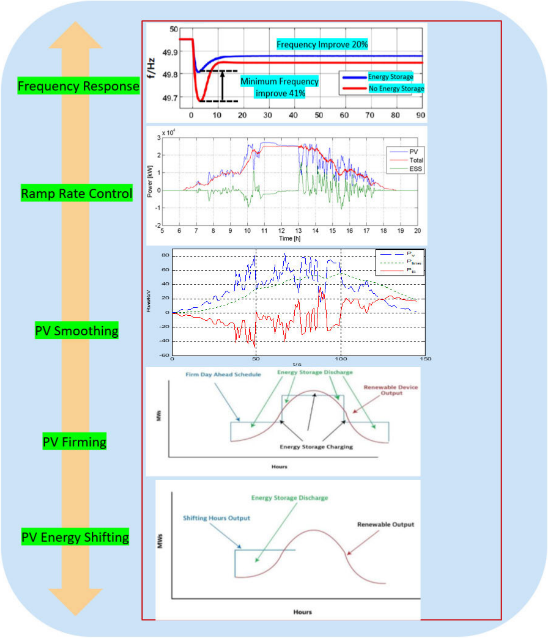


FIGURE 1. Five functions of storage in PV plants.

regulation [18]–[25], which supports the grid against disturbances and faults. Storage could correct over and under frequency, prevent black-outs and costly equipment damage due to its fast response times and high flexibility. Among them, Automatic Generation Control (AGC) frequency modulation requires the frequency modulation source to perform a fast power ramp to quickly follow the AGC command with a large output, so the battery-type energy storage needs to have high-rate characteristics. In addition, the characteristics of energy storage safety, power density, cost, conversion efficiency, etc. need to be considered.

B. POWER RAMP RATE CONTROL

The power fluctuations of renewable energy sources such as photovoltaics put tremendous pressure on the grid [23]–[34]. The ramp rate of traditional units is often difficult to balance the large short-term power fluctuations brought about by renewable energy. Transmission companies and power departments in many countries in the world have set clear requirements for the active power ramp rate of PV power plants. For example, in 2012, China required PV power plants with an installed capacity of 30 ∼ 150MW, the maximum value of active power change within 10 minutes should not exceed 1/3 of the installed capacity; With the continuous maturity of energy storage technology, the use of energy storage systems to shift the power fluctuations of renewable energy can effectively alleviate the pressure of frequency regulation and peak regulation of the power grid.

C. PV POWER OUTPUT SMOOTHING

Use the energy storage system to quickly absorb or release energy, smooth the PV grid-connected power generation voltage fluctuations, improve the active power and reactive power balance levels of the system, and enhance stability [35]–[42]. PV power generation can take appropriate energy storage configuration and reasonable coordination strategies to improve the smoothing effect. Energy storage capacity is generally determined by PV grid-connected smoothing strategies and energy dispatching strategies. Generally, if it is only to achieve the effect of smooth output, the capacity of the energy storage system is relatively small, and the mathematical model algorithm, control mode and response speed of the system will be higher.

D. PV CAPACITY FIRMING

The installation of energy storage in large-scale PV power stations can enhance the dispatchability of PV power stations. Energy storage system enable PV plants to firm their hourly energy production and avoid in this way the economic penalties associated with deviations between the contracted commitment made by the renewable generator to the grid and the final energy delivered [43]–[49].

E. ENERGY SHIFTING

Energy transfer refers to displace excess production to times when there is high demand and low production (peak shaving) [50]–[52]. Energy shifting is increasingly the major driver for utility-scale deployments. Many projects that provide peaking capacity are also tagged as energy shifting because of the overlap between these applications.

III. PV PLUS STORAGE SYSTEM MODELING

A. OBJECTIVE FUNCTIONS

To evaluate the economic benefits of large-scale PV plus storage systems, it is necessary to compare the costs and benefits of system configuration. The cost of the system is mainly composed of equipment cost, material cost, installation cost and various grid connection and development procedure fees. The revenue is related to the services that the system can provide. Different application forms will produce different values. Such as energy market, capacity market, ancillary service market, etc., need to determine the application mode according to the specific power market structure and regulatory requirements. Especially in the energy market, system returns may vary greatly in different situations.

This article establishes a comprehensive objective function, considering NPV, internal rate of return (IRR), Benefits-Cost ratio (BCR) and so on. A double layer decision model architecture is proposed as Figure 2 shown. The outer optimization objectives are 4 indicators of NPV, investment payback period (PBP), IRR and BCR, and the optimization variable is energy storage scale. The inner optimization goal is initial cost of energy storage, the optimization variable is the energy storage operation curve, the battery degradation curve and augmentation strategy.

The indicators of outer optimization objectives to assess the overall economics of the system include:

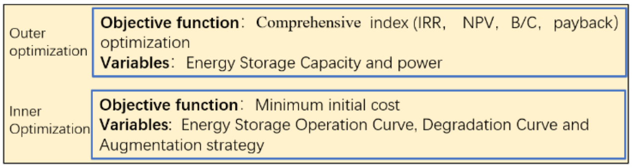


FIGURE 2. **Double-layer decision model architecture.**

1) NPV measures the economic viability of the project in N years by using the nominal discount rate to add the converted cash flow to the converted cash flow in the first year.

2) IRR is the nominal discount rate, which corresponds to zero NPV.

3)BCR, which is the present value of benefits divided by the present value of costs

$$NPV = \sum_{t=1}^{n} (CI - CO)_t (1+IRR)^{-t} = 0 \tag{1}$$

CI-cash inflow in year t.

CO-cash expenditure in year t

4) The payback period refers to the period for the recovery of the investment of the energy storage project, that is, the time required for the net cash inflow generated by the investment of the energy storage project to recover the entire initial investment.

The optimization objective function of the inner layer is the lowest energy storage cost.

The cost of the energy storage system is the sum of the initial investment cost and the operation and maintenance cost:

$$C = C_{capital} + C_{OM} \tag{2}$$

$C_{capital}$ is the energy storage system investment cost,
C_{OM} the system operation and maintenance cost.

B. CONSTRAINT

1) POWER BALANCE CONSTRAINTS

Grid-connected power is equal to the sum of PV and energy storage output.

$$P_{grid}(t) = P_{pv}(t) + P_{ESS}(t) \tag{3}$$

2) ENERGY STORAGE POWER CONSTRAINTS

The energy storage charge and discharge power is limited by the maximum conversion power of the converter

$$-P_{max} \leq P_{ESS} \leq P_{max} \tag{4}$$

P_{max} Maximum discharge power for energy storage system

3) ENERGY STORAGE CHARGE CONSTRAINTS

To avoid excessive charging and discharging of energy storage, run between the minimum and maximum charge state of energy storage.

$$-SOC_{min} \leq SOC(t) \leq SOC_{max} \tag{5}$$

SOC_{min} Energy storage system minimum charge state,
SOC_{max} energy storage system maximum state of charge.

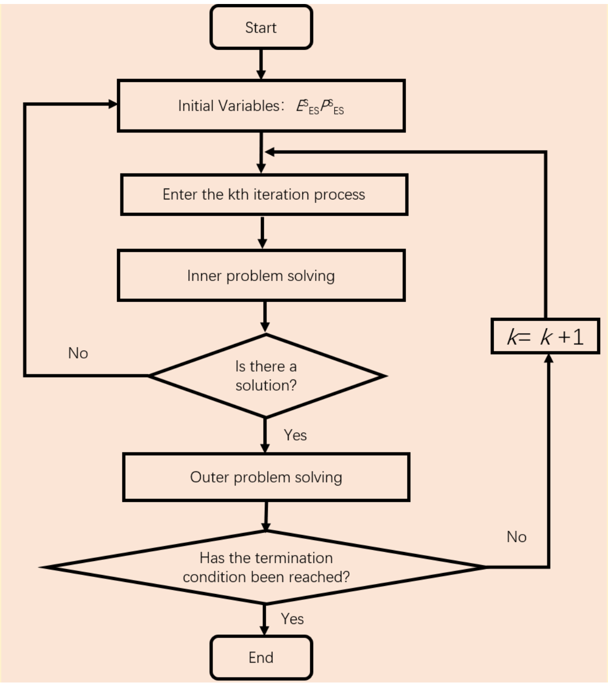


FIGURE 3. **Storage configuration process based on double-layer decision model.**

The setting of the two parameters is to avoid overcharge and over-discharge of energy storage.

C. ENERGY STORAGE SYSTEM CONFIGURATION FLOW CHART

Figure 3 shows the energy storage configuration process of the optical storage system based on double-layer decision model. Because it is difficult to obtain the global optimal solution by using the bi-level programming model, the numerical calculation method is used to iterate directly with a fixed number of steps. When a certain convergence condition is met, the optimal solution is considered. In the figure, Es and Ps respectively represent the initial capacity and power configuration of energy storage system.

D. PV GENERATION MODELING

8760 hourly solar generation is produced by PVsyst for PV plus storage modeling. PVSYST [53] analyzes the power generation of PV power plants based on historical data, which conforms to the normal distribution. The P50 - P90 evaluation is a probabilistic approach for the interpretation of the simulation results over several years. For example, the probability of a photovoltaic power station reaching 1385.92MWh is 50%, and the probability of reaching 1299.7MWh is 90%. If the weather data we import into the software is close to the actual multi-year average value, then the P50 value can be used. On the contrary, if the imported meteorological data is only the value of a special year, we must either increase the probability of occurrence of the event to estimate it, such as selecting P90, or make a deviation correction based on the actual value of the surrounding stations.

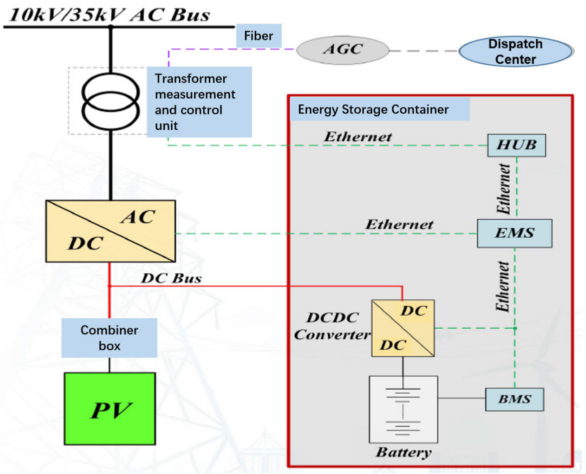
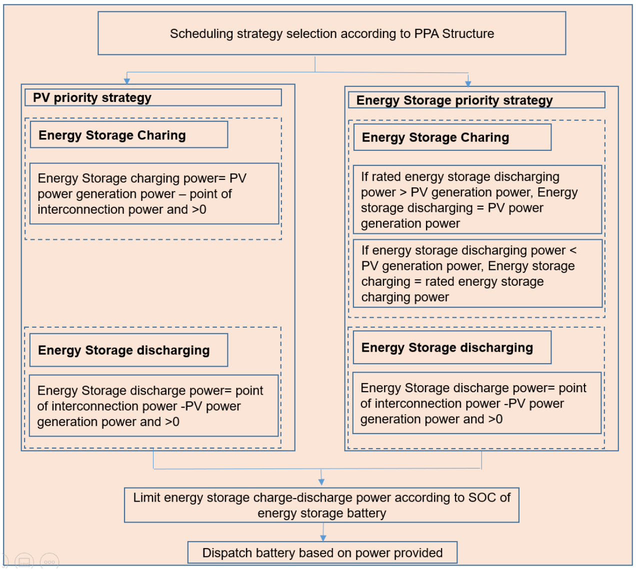


FIGURE 4. DC-coupled PV plus storage system charging and discharging topology diagram.


Scheduling strategy selection according to PPA Structure

PV priority strategy

Energy Storage Charing

Energy Storage charging power= PV power generation power – point of interconnection power and >0

Energy Storage discharging

Energy Storage discharge power= point of interconnection power -PV power generation power and >0

Energy Storage priority strategy

Energy Storage Charing

If rated energy storage discharging power > PV generation power, Energy storage discharging = PV power generation power

If energy storage discharging power < PV generation power, Energy storage charging = rated energy storage charging power

Energy Storage discharging

Energy Storage discharge power= point of interconnection power -PV power generation power and >0

Limit energy storage charge-discharge power according to SOC of energy storage battery

Dispatch battery based on power provided

FIGURE 5. How the dispatch controller decides to charge or discharge the battery.

E. ENERGY STORAGE SYSTEM MODELING

Energy storage system modeling includes battery models, dispatch control models, and battery degradation models.

1) BATTERY MODELING

Due to high efficient system with safe and long lifecycle Lithium Iron Phosphate (LFP)battery is used widely for PV project in the world. The cycle life will be more than 6000 cycles under full depth of discharge (DOD). System round-trip efficiency is 90%

An energy storage system based on LFP battery cells. Includes integrated Battery Management System (BMS) for management of and communication with the batteries, DC bussing, overcurrent protection, and disconnecting means, a thermal management system with heating and cooling capabilities, an industrial controller (LCC – local container controller) for local control and communication interface with external Supervisory control and data acquisition (SCADA), and fire detection and mitigation measures.

As Figure 4 shown, the energy is delivered from PV to battery by single DC-DC converter when charging; while the energy is transmitted from battery into power grid by DC-DC converter and DC-AC converter plus one transformer when discharging. Total round-trip efficiency is about 93.5%.

2) DISPATCH CONTROL STRATEGY

According to Power Purchase Agreement (PPA) structure in different regions, two dispatching control strategies for energy storage have been formulated, namely PV power generation priority output strategy and energy storage priority charging strategy. When the PV power generation and energy storage discharge electricity prices are the same, the "PV power generation priority output strategy" is adopted; when the local grid connection policy requires or the energy storage discharge electricity price is high, and the energy storage configuration is more cost-effective, the energy storage priority charging strategy is adopted. As shown in Figure 5

When the revenue from direct delivery of PV power generation is greater than the revenue from energy storage, the priority output strategy of PV power generation is adopted. When charging, Energy Storage charging power equal to PV power generation power-point of interconnection power and larger than 0; When discharging, Energy Storage discharge power = point of interconnection power-PV power generation power and larger than 0

When the revenue from direct delivery of PV power generation is less than the revenue from energy storage, and the project site policy encourages energy storage to have additional revenue, the energy storage priority charging control strategy is adopted. In the state of charge, PV power generation gives priority to charging for energy storage. When the energy storage charging rated power is greater than the PV power generation power, energy storage charging power equal to PV power generation power; when the energy storage charging power is less than the PV power generation power, energy storage charging power equal to energy storage rated charging power. In the discharge state, Energy Storage discharge power equal to Point of Interconnection power - PV power generation power and larger than 0

Finally, the energy storage SOC state is combined to limit the charging and discharging power, and the battery scheduling strategy is worked out.

3) BATTERY DEGRADATION MODEL

Energy storage expansion strategy is to maintain the performance of the energy storage system throughout the life cycle, through the battery hot standby strategy, or energy storage into the system or energy storage exit system or add additional energy storage capacity on the basis of the original system.

Some projects may require battery replacement within 15 years, while others may take longer. Therefore, energy storage augmentation strategies need to consider different cycle life, technical routes, and specific application scenarios in order to formulate corresponding plans and budgets.

In order to ensure the stable energy storage output of the optical storage power station, it is necessary to ensure that the available capacity of the energy storage system in the nth year is greater than or equal to the required lower limit output capacity value.

$$C_{rea}\left(n\right) > C_{min} \tag{6}$$

where: C_{min} the lower limit output capacity value of the energy storage system

$C_{rea}\left(n\right)$ Available capacity of the energy storage system in the nth year

C_{Ori} the initial capacity of the energy storage system in year 0.

The available capacity of the energy system in the nth year is

$$\begin{aligned} C_{rea}(n) = {} & C_{ori\_rea}(n-1)\cdot\eta_{ori}\left(n\right) \\ & + \sum_{i=1}^{m} C_{Aug\_rea}(n-1)\cdot\eta_{Aug}\left(n\right) \end{aligned} \tag{7}$$

$$C(n) = C(0)\cdot\left(\eta_1\cdot\eta_2\cdots\eta_n\right) \tag{8}$$

where: $C_{ori\_rea}(n)$ is the available capacity in the nth year of the initial installation of the battery.

$C_{Aug\_rea}(n)$ is the available capacity of the increased battery in the nth year

$\eta_{ori}\left(n\right)$ Is the capacity degradation coefficient of the nth year when the battery is initially installed

$\eta_{Aug}\left(n\right)$ Is the capacity degradation coefficient of the capacity increasing battery in the nth year.

4) STORAGE INVERTER MODELING AND CONTROL

The structure of the energy storage inverter is the similar to the PV inverter, using a double closed-loop controller, the power outer loop controls the active power and reactive power to realize the tracking of the command reference; the current inner loop makes the output current track the current reference command. The structure block diagram of the inverter controller is shown in Figure 6.

IV. CASE STUDY

We performed a case study to evaluate the sizing of Energy Storage capacity for PV power plant. The base set of assumptions is listed in Table 1, The project has a PV installed capacity of 140MWac / 240MWdc, a PV module model of CS3U-360P G4, and a PV inverter using SG2500UD. PV performance parameters were derived from [24]. Based on the 2016-2019 Local Marginal Price (PML) and Congestion price data, the monthly average daily electricity price of each year is filtered and analyzed. The monthly average electricity price of 2016-2019 is close to the monthly average electricity price of 2019, and the data of electricity price in 2019 is up to date. Therefore, the electricity price data in 2019 (Figure 7) is selected for calculation and the electricity price model is established.

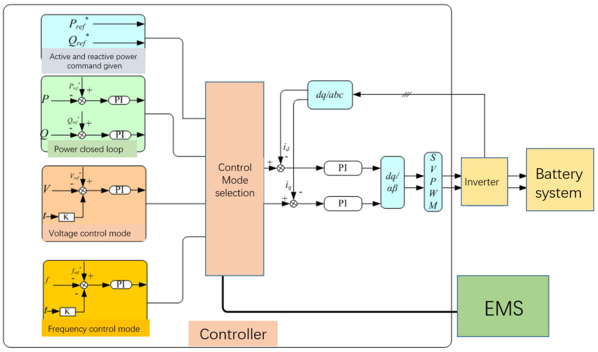


FIGURE 6. The structure block diagram of storage inverter controller.

TABLE 2. Key assumptions.

No.	System Specifications	
1	Solar Storage System	
1.1	Generation analysis period	25 years
1.2	Storage analysis period	20 years
1.3	POI Limit	129.74MW
1.4	Battery + PV coupling	DC-coupled
2	PV system	
2.1	PV inverter power AC	140MW
2.2	Panel size	239.8MWp
2.3	PV capacity ratio	1.71
3	Energy storage system	
3.1	Type of battery	LFP Prismatic
3.2	Cycle Life (Full DOD Cycles to 80%)	3500
4	Electricity price and cost	
4.1	Electricity price	Local Marginal Prices of 2019
4.2	Unit PV cost	$ 0.563 /Wp
4.3	Unit Storage cost	$ 221.13 /kWh
4.4	Debt Method	No Debt
4.5	Capacity price	$ 3.7 / kW-mo

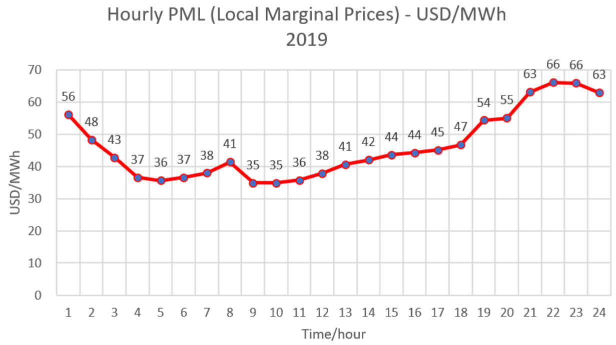


FIGURE 7. The electricity price data in 2019.

The optimal power capacity of the energy storage system is calculated according to the energy storage configuration flow chart based on two-layer decision architecture shown in Figure 3. With the increase in the scale of energy storage, the investment cost is gradually increasing. Using the proposed model and algorithm, the calculation results of each index are shown in Figure 8. The following results can be drawn from Figure 8,

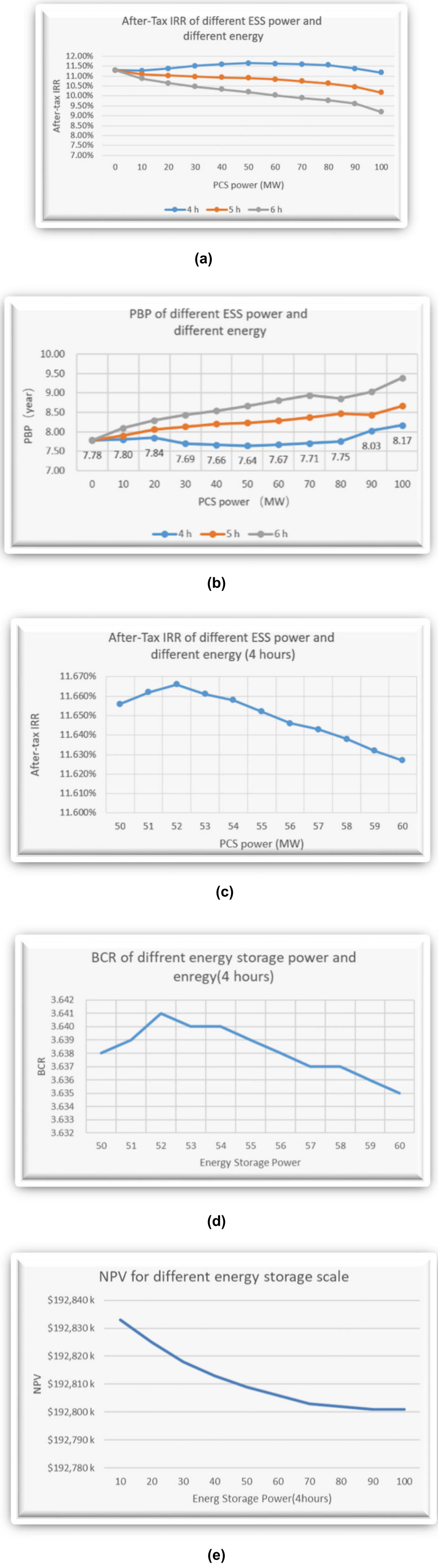
- According to Figure 8(a) and Figure 8(b), different hours systems are compared, 4hours, 5hours and 6 hours system are modeling and calculated, 4hours system is more economic.
- As shown in Figure 8(b), when the energy storage configuration is 52MW / 208MWh, the shortest payback period of the PV energy storage system investment is 7.64 years. The PBR curve first drops and then rises.
- According to Figure 8(c), with 52MW / 208MWh energy storage configured, the system internal rate of return (after-tax IRR) is the highest at 4 hours of charge and discharge, approximately 11.666%. The IRR curve first rises and then falls.
- According to Figure 8(d), the more energy storage configuration, the smaller the NPV. The optimal energy storage scale cannot be got using NPV index. Therefore, the BCR needs to be evaluated.
- According to the relationship between the energy storage power of the storage system and the Benefit/Cost as shown in Figure 8(e), when the energy storage configuration is 52MW / 208MWh, the Benefit/Cost ratio is the largest, about 3.641. The trends of BCR and IRR are consistent firstly up and then down.

The battery was oversized by 20% and augmented periodically to maintain 208 MWh of available capacity (full power over four hours) while cycling within 80% depth-of-discharge limits.

According to the degradation characteristics of the battery, system capacity requirements, battery cost, etc., the battery capacity augmentation is established. In the 8th year, the capacity expansion installation is 31.2MWh (15% of the initial installation energy), and in the 16th year capacity expansion installation is 37.44MWh (18 % of the initial installation energy) to ensure that the energy storage capacity in the 25th year meets the requirements (Figure 9).

The DC/AC ratio of PV plus storage system is different with DC/AC ratio of PV system. Our findings (Figure 10) are as follows on DC/AC ratio impact on IRR of PV with 52MW/208MWh storage system according to the Figure 3.

- The IRR of only PV system reaches about 14% when the PV capacity ratio is 1.3.
- When DC/AC ratio is less than 1.7, the ESS will lower the project IRR; it is not recommended to consider ESS when the DC/AC ratio is less than 1.7.
- When the PV capacity ratio is ≥ 1.7, as the ESS capacity increases, the IRR first decreases and then rises.



(a) (b) (c) (d) (e)

FIGURE 8. Calculated results for each indictor (a) IRR of different power and different energy. (b) PBP of different power and different energy. (c) After-tax IRR of different power and different energy for 4 hours. (d) NPV of different energy storage scale. (e) BCR of different power and different energy for 4 hours.

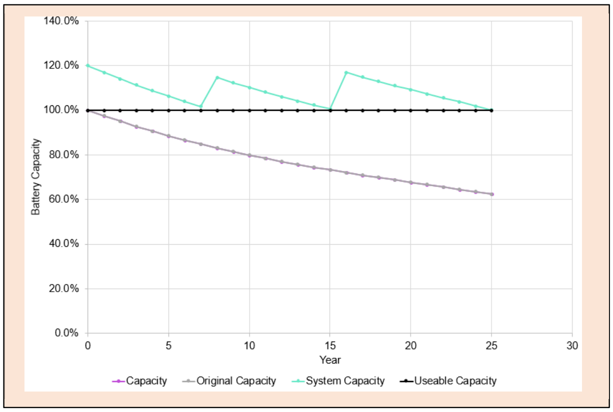


FIGURE 9. Calculated results for each indictors (a) After-tax IRR of Capacity available, assuming 80% depth of discharge over a 25-year project for both battery configurations augmented in year 8 and 16 to maintain 208 MWh.

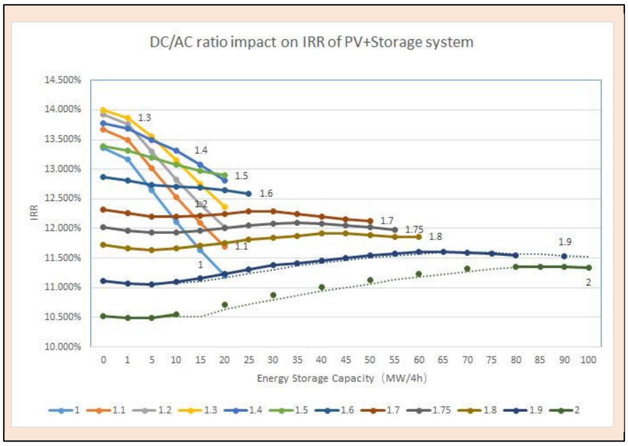


FIGURE 10. DC/AC ratio impact on IRR of PV plus storage system.

Different PV DC/AC ratios have the ESS capacity matching the highest IRR.

- As the PV DC/AC ratio increases, the capacity of the ESS matching its highest IRR will increase, and the highest IRR value will continue to decrease.

V. CONCLUSION

This paper proposes an energy storage capacity optimization method based on a double-layer decision architecture. The inner layer takes the energy storage degradation curve and augmentation strategy as variables and takes the minimum investment cost the objective function. Inner optimization can reduce system investment by 5%-10% by optimizing the augmentation model. The outer layer uses energy storage scale as a decision variable, and NPV, IRR, B/C, and PBP as a comprehensive objective function. The outer layer optimization adopts comprehensive index evaluation. The proposed comprehensive index avoids the limitations of single index evaluation. Starting from the actual situation of investors, the feasibility of energy storage projects can be evaluated as a whole, and an appropriate energy storage scale can be proposed.

With the development of energy storage technology, future analysis will also consider more detailed cycle-life degradation representation and different approaches to battery augmentation.

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