# Hybrid Storage System Planning for Power Quality Improvement in Power Distribution System with Solar Photovoltaic Sources

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**Abstract.** The distributed photovoltaic sources have demonstrated the benefits of clean and environmental protection, flexible construction, nearby utilization and small impact on the power grid. It is considered of paramount importance to optimize the energy provision and efficiency as well as the emission reduction to realize the low carbon energy provision. In this paper, an algorithmic solution for sitting and sizing of hybrid storage systems in power distribution systems has been developed and presented. The proposed solution is evaluated through the IEEE-33 test network, and the numerical result clearly confirmed the effectiveness of the proposed solution in appropriately allocating the energy storage systems for improving the power quality in active distribution systems with distributed solar energy resources.

**Keywords:** Hybrid storage system · Power distribution systems · Power quality · Photovoltaic power generation

## 1 Introduction

New green energy has the characteristics of green environmental protection, which can effectively avoid the disadvantages of traditional energy combustion, but there are still many problems. In addition to nuclear energy, wind energy and light energy cannot provide stable energy output like coal, and it is difficult to control, so it is easy to affect the operation of the power grid once the renewable resources are connected with the grid. Even in island operation mode, it cannot provide stable power to the load. With the development of power electronics technology and modern control theory, microgrid as effective access to distributed generation and organization management has become an effective way to solve the above defects.

As widely used energy storage equipment, the battery has a large energy density, which can provide more energy. However, it should be noted that the power density of the battery is generally small, and the flexibility of power charging and discharging are not satisfactory in practice. This indicates that, under the condition of sudden load variations, the battery cannot release or absorb the target power as quickly as expected, and the dynamic performance of the system is poor. On the contrary, the super-capacitor

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has a smaller energy density but higher power density, which can discharge power energy in a very short time. The composite energy storage system composed of a battery and supercapacitor improves the overall performance and enables fast response and large stable power supply.

With the rapid and massive deployment of distributed photovoltaic power sources in the medium and low voltage power distribution networks, the traditional distribution network has been transformed into an active distribution network [1–4]. The battery has been developed and adopted for years and are considered can meet the energy density requirements. However, due to the limited electrochemical reaction rate, the battery power density is often considered small, and hence cannot absorb or release the power as expected. Under the condition of load demand variations, the batteries cannot meet the dynamic requirements of the system. During the charging and discharging of the supercapacitor, the internal changes are physical, which has the characteristics of high power density. It can provide large power in a short time and provide a buffer for other equipment, but the energy density is relatively low. Therefore, the supercapacitors and batteries have been considered to work in a complementary manner. These two types of energy storage units can be connected to form a composite energy storage system. This can provide the benefits of both types of energy storage units to obtain better performance. On the one hand, the massive connection of distributed photovoltaic sources to the distribution network, there will be large power instantaneous fluctuation in the distribution network. The supercapacitor provides short-time power grid energy support; On the one hand, for the long-time power fluctuation of the distribution network, the battery provides the power grid energy support. On the one hand, the energy storage system can provide reactive power compensation and improve power quality when there are power quality problems or reactive power shortages in the distribution network area. Especially after the popularization and application of the new generation of the intelligent distribution automation system, the access of low-voltage distribution network terminal devices has gradually become a trend. This work takes this as the starting point to develop the integrated device of composite energy storage and reactive power compensation, aiming to address the aforementioned technical challenge induced by the massive penetration of high power density distributed generation.

It is widely agreed that the massive connection and access to distributed photovoltaic power can directly bring a great impact on the power quality of the power supply (e.g., [5–10]). In practice, the transformer capacity in the distribution network area is limited, and the ability to resist the interference of large load impact and the ability of instantaneous large power fluctuation is weak, especially in the power grid under the condition of high power density distributed photovoltaic access, it is difficult to meet the impact of large instantaneous power fluctuation of distribution network. In this paper, the main technical contributions are as follows:

(1) This paper proposes an optimization model with multiple objectives for location planning of energy storage system.
(2) The corresponding algorithm is developed to implement the location of energy storage systems and ensure that the system power fluctuation is in the optimal range. Taking the node voltage as power quality index, the power quality is exploited and evaluated through quantitative analysis.

## 2 Hybrid Storage Systems and Configuration

The typical composite energy storage for the power distribution system with photovoltaic power generation sources is shown in Fig. 1. The photovoltaic module plays the role of energy conversion to convert the solar energy into electric energy. The unidirectional DC-DC converter can boost photovoltaic power generation unit and can work in the maximum power point tracking mode to maximize resource utilization. The bidirectional DC-DC converter can control the charging/discharging actions of the energy storage system. It can convert direct current into alternating current, and the transformer can convert the alternating current into suitable voltage to supply power for the load. Also, the system is connected to the power grid through a common connection point. In this section, the independent operation mode of composite energy storage photovoltaic power generation system is considered.

The power quality degradation induced by the massive penetration of distributed photovoltaic sources mainly includes voltage overrun and harmonic pollution. The sitting and sizing of the composite energy storage systems need to fully consider the economy of the composite energy storage system and the effect of improving power quality.

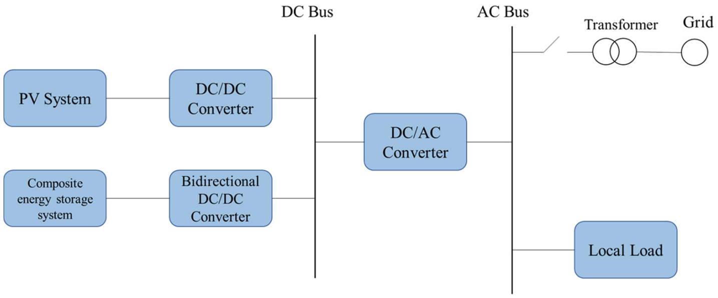

**Fig. 1.** Composite energy storage system in the photovoltaic power generation system

## 3 Optimal Planning of Hybrid Storage in Distribution Systems

### 3.1 Objective Function

### 3.1.1 Node Voltage Deviation

The high photovoltaic output will lead to the voltage limit of some nodes. Therefore, this paper selects the sum of node voltage deviation as one of the objective functions of location and capacity determination of composite energy storage system as follows:

$$f_U = \sum_{i=1}^{N} \sum_{j=1}^{T} |U_{ij} - U_N| \tag{1}$$

Here, $N$ and $T$ are the number of system nodes detection time; $U_{ij}$ is the voltage of $i$ node at time $j$, and $U_N$ is the rated system voltage.

### 3.1.2 Total Harmonic Distortion Rate of Current

The photovoltaic sources require a large number of power electronic inverters connected to the distribution network. As a result, the total harmonic distortion rate of the current is considered that can be formulated as follows:

$$f_{THD_1} = \frac{\sqrt{\sum_{h=2}^{M} I_h^2}}{I_1} \times 100\% \tag{2}$$

Where $I_h$ and $I_1$ are the root mean square of the $h^{th}$ harmonic current and the fundamental current.

### 3.1.3 Cost of Composite Energy Storage System

The cost and the power quality management need to be considered in the composite energy storage system. The total cost is formulated as (3)

$$f_P = c_1 \frac{P_c}{\eta_1} + c_2 \frac{P_b}{\eta_2} + c_m P_{sum} \tag{3}$$

Where, $P_c$ and $P_b$ is the capacity of supercapacitor and battery to be configured in the system; $\eta_1$ and $\eta_2$ represent the energy conversion efficiency of supercapacitor and battery, respectively; $c_1$ and $c_2$ are the price of the unit capacity of supercapacitor and battery; $P_{sum}$ is the total capacity of the composite energy storage system, and $c_m$ represents the daily maintenance cost of the composite energy storage system.

Therefore, the node voltage deviation, total harmonic distortion rate of the current and total cost of composite energy storage are considered in the formulation of the the multi-objective optimization model, that can be expressed in (4).

$$\begin{cases} \min F = \alpha f_U + \beta f_{THD_I} + \gamma f_P \\ \alpha + \beta + \gamma = 1 \end{cases} \tag{4}$$

Here, $\alpha$, $\beta$ and $\gamma$ are the normalized weight coefficients.

## 3.2 Constraints

### 3.2.1 Node Voltage

The voltage of each node in the system should be maintained within a certain range

$$V_{\min} \leq V_i \leq V_{\max} \tag{5}$$

Where, $V_i$ is the voltage of the $i$ node, and $V_{\min}$ and $V_{\max}$ are the lower limit and upper limit of the system voltage, which are determined by the system's requirements for voltage overrun.

### 3.2.2 Power Balance

Power balance should be maintained in the system at any time, that is:

$$P_S = \sum_{i=1}^{N} P_{Li} - \sum_{j=1}^{L} P_{DG_j} - \sum_{k=1}^{M} P_{storek} \tag{6}$$

Among them, $P_S$ is the total power of input distribution network, $P_{Li}$ is the load power of $i^{th}$ node; $P_{DG_j}$ is the distributed photovoltaic output of the $j^{th}$ node; $P_{storek}$ is the capacity of the $k^{th}$ composite energy storage system, and is positive when the energy storage is discharged.

### 3.2.3 Composite Energy Storage Power Constraint

There are upper and lower limits for the power provided by the hybrid energy storage system

$$P_{oc\_\min} \leq P_{oc\_i} \leq P_{oc\_\max} \tag{7}$$

Among them, $P_{oc\_\min}$ and $P_{oc\_\max}$ are the lower and upper limits of the output power of composite energy storage systems.

## 4 Experiments and Numerical Results

This work adopted the IEEE-33 bus test network for the performance assessment and analysis. In the test network, the total active and reactive loads are 3715.0 kW and 2300.0 kvar, respectively. The system voltage reference value is 12.66 kV. The installation location of distributed photovoltaic sources is shown in Fig. 2. It is assumed that all the nodes are connected with the distributed photovoltaic sources with a capacity of 300 kW.

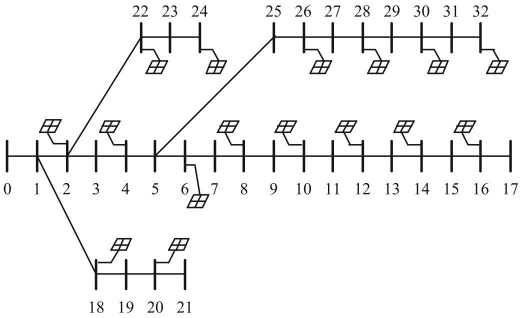

**Fig. 2.** Experimental IEEE-33 node distribution system

In the simulation of this paper, in principle, the composite energy storage system is allowed to access 1–32 nodes. On the one hand, the composite energy storage system composed of the supercapacitor and lead-acid battery uses the rapid response ability of the supercapacitor to meet the high-power fluctuation, on the other hand, it uses the relatively low cost of the lead-acid battery to stabilize the system fluctuation and control harmonics. Considering the node voltage deviation, total harmonic distortion rate of the current and total cost of composite energy storage system, the node sensitivity analysis method is applied to select four node-set including {25, 30, 13, 20} The maximum installed power is 600 kW.

In this study, for {25, 30, 13, 20} and the other four nodes, the improved particle swarm optimization algorithm is implemented to adopted to obtained the composite energy storage installation location and capacity. The numerical results are presented in Table 1.

**Table 1.** Installation position and capacity of composite energy storage device

| Node | Rated power/kW |
|---|---|
| 25 | 570 |
| 30 | 554 |

Further, the power quality control indexes of the distribution network before and after the installation of composite energy storage devices in the test network are calculated, as shown in Table 2.

**Table 2.** Power quality control index of distribution network

| Power quality measures | Before storage installation | After storage installation |
|---|---|---|
| Node voltage deviation/pu | 1.1570 | 0.9203 |
| Total harmonic distortion rate of current/% | 0.6815 | 0.2516 |

## 5 Conclusions

This paper proposed an algorithmic solution for sitting and sizing of hybrid storage systems in power distribution systems. Through the study, it can be concluded that the composite energy storage cannot only effectively solve the voltage overrun caused by distributed photovoltaic, but also suppress harmonics, which can meet the demand of high power density distributed photovoltaic access to the distribution networks.

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## References

1. Paatero, J.V., Lund, P.D.: Effects of large-scale photovoltaic power integration on electricity distribution networks. Renew. Energy **32**(2), 216–234 (2007)
2. Brekken, T.K.A., Yokochi, A., Jouanne, A.V., et al.: Optimal energy storage sizing and control for wind power applications. IEEE Trans. Sustain. Energy **2**(1), 69–77 (2011)
3. Teleke, S., Baran, M.E., Bhattacharya, S., et al.: Optimal control of battery energy storage for wind farm dispatching. IEEE Trans. Energy Convers. **25**(3), 787–794 (2010)
4. Demirören, A., Zeynelgil, H.L., Sengör, S.N.: The application of neural network controller to power system with SMES for transient stability enhancement. Int. Trans. Electr. Energy Syst. **16**(6), 629–646 (2006)
5. Kanchev, H., Lu, D., Colas, F., Lazarov, V., Francois, B.: Energy management and operational planning of a microgrid with a PV-based active generator for smart grid applications. IEEE Trans. Ind. Electron. **58**(10), 4583–4592 (2011)
6. Mohamed, F.A., Koivo, H.N.: System modelling and online optimal management of microgrid using mesh adaptive direct search. Int. J. Electr. Power Energy Syst. **32**(5), 398–407 (2010)
7. Nunna, H.K., Doolla, S.: Energy management in microgrids using demand response and distributed storage–a multiagent approach. IEEE Trans. Power Del. **28**(2), 939–947 (2013)
8. Jiang, Q., Xue, M., Geng, G.: Energy management of microgrid in grid-connected and stand-alone modes. IEEE Trans. Power Syst. **28**(3), 3380–3389 (2013)
9. Mahmoodi, M., Shamsi, P., Fahimi, B.: Economic dispatch of a hybrid microgrid with distributed energy storage. IEEE Trans. Smart Grid **6**(6), 2607–2614 (2015)
10. Vasilj, J., et al.: Day-ahead scheduling and real-time economic MPC of CHP unit in microgrid with smart buildings. IEEE Trans. Smart Grid **10**(2), 1992–2001 (2019)