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OPTIMIZED CONFIGURATION OF ENERGY STORAGE IN AC-DC DISTRIBUTION SYSTEM WITH HIGH PENETRATION PVS INTEGRATED

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ABSTRACT

DC power distribution technology and energy storage technology can promote the safe integration of renewable energy. In this paper, a scene clustering based bi-layer energy storage optimal configuration method for AC-DC distribution system with high-penetration PVs is proposed. The upper storage capacity allocation model aims at minimizing the sum of annual investment cost and operation cost, while the lower level operation optimization model is to minimize the system annual operation cost. This paper applies the model of BESS configuration to the AC-DC distribution system, and discusses the influence of DC distribution technology, VSC control characteristics and load distribution on the BESS configuration results through several examples.

Keywords: AC-DC distribution system, Energy storage system, photovoltaic, Scenario analysis

NOMENCLATURE

Abbreviations	
VSC	Voltage Source Converter
BESS	Battery energy storage system
C_{inv}	Annual investment and maintenance of BESS
C_{ope}	Annual operation cost of the AC-DC distribution system
$P_{\mathrm{VSC,AC}}$ / $P_{\mathrm{VSC,DC}}$	Active power from AC/DC side of VSC
S_{VSC}	Capacity of VSC
$P_{\mathrm{VSC,loss}}$	Active power loss of VSC
r_{ij} / x_{ij}	Resist/reactance of branch *ij*
P_{ij} / Q_{ij}	Active/reactive power flow from node *i* to node *j*
$P_{B.charge}$ / $P_{B.discharge}$	Charging/discharging power of BESS

1. INTRODUCTION

Energy storage technology, which can both realize peak shaving and valley filling and reduce fluctuation of renewable energies, plays a critical role in electric system. At the same time, compared with the traditional AC distribution system, AC-DC distribution system can effectively improve flexibility, controllability, economy and security of the system operation, and is a favorable technical means to deal with plenty of distributed generation access.

Energy storage technology has a wide application in electric system. In reference [1-2], energy storage is configurated in system to suppress short term power fluctuations with reducing impact on cycle life of energy storage at the same time, but total cost of system is not taken. Reference [3] orients to microgrid to configurate BESS to realize peak shaving and valley filling, however, it doesn’t take investment of BESS into account. Reference [4] optimizes the place and capacity of energy storage connected in an electric system to reduce congestion of branches and enhance flexibility of loads, but the model is to judge whether branch power flow off-limit is simple With the application of BESS and DC distribution technology, there is no doubt that the consumption level of photovoltaic power generation in the distribution system will be greatly improved. But there are few studies about BESS configuration in AC-DC distribution system with high-penetration PVs.

In view of the high cost of energy storage system, this paper proposes an energy storage configuration model which takes into account the coordinated operation with VSC and absorbs a high penetration of photovoltaic output, and considering the two stages of planning and operation, a bi-level optimal configuration model of BESS is established. Parameters of VSC of the lower level model can be adjusted to optimize system operation with BESS in the meanwhile. In this paper, the influence

DC distribution technology and loads distribution on BESS configuration is studied.

2. SYSTEM MODELS

2.1 The second-order cone model of AC-DC distribution system Disflow

In AC distribution system, branch power flow equation, nodal voltage equation and branch current equation are following:

$$\begin{cases}\sum_{j\in\varphi_i} P_{ij}(t)=\sum_{k\in\psi_i}[P_{ki}(t)-I_{ki}^2(t)\times r_{ki}]-\mathrm{P}_{is}(t)\\ \sum_{j\in\varphi_i} Q_{ij}(t)=\sum_{k\in\psi_i}[Q_{ki}(t)-I_{ki}^2(t)\times x_{ki}]-Q_{is}(t)\end{cases} \tag{1}$$

$$\begin{aligned}U_{\mathrm{j}}^2(t)=U_i^2(t)-2\times[r_{ij}\times P_{ij}(t)+x_{ij}\times Q_{ij}(t)]\\ +(r_{ij}^2+x_{ij}^2)\times I_{ij}^2(t)\end{aligned} \tag{2}$$

$$I_{ij.ac}^2(t)=\frac{P_{ij}^2(t)+Q_{ij}^2(t)}{U_i^2(t)} \tag{3}$$

In DC distribution system, branch power flow equation, nodal voltage equation and branch current equation are following:

$$\sum_{j\in\varphi_i} P_{ij}(t)=\sum_{k\in\psi_i}[P_{ki}(t)-I_{ki}^2(t)\times r_{ki}]-\mathrm{P}_{is}(t) \tag{4}$$

$$U_{\mathrm{j}}^2(t)=U_i^2(t)-2\times r_{ij}\times P_{ij}(t)+r_{ij}^2\times I_{ij}^2(t) \tag{5}$$

$$I_{ij.dc}^2(t)=\frac{P_{ij}^2(t)}{U_i^2(t)} \tag{6}$$

Control mode of VSC is shown in Tab 1.

Tab 1 Control mode of VSC

Control mode	AC node type	DC node type
PQ	PQ	Constant power
PU_{ac}	PV	Constant power
$U_{dc}Q$	PQ	Constant power
$U_{dc}U_{ac}$	PV	Constant power
$U_{ac}\theta$	$V\theta$	Constant power
Mϕ	-	-

In this paper, AC-DC distribution system has two VSCs, one of whose control mode is PQ while the other is $U_{dc}Q$. Active power of control mode of PQ can be adjusted to contribute to optimizing operation.

In addition, the power balance in VSC is shown as equation (7):

$$P_{VSC.\mathrm{dc}}=P_{VSC.ac}-P_{VSC.loss} \tag{7}$$

2.2 Model of electrical energy storage system

Charging and discharging powers of stored energy are:

$$P_{B.\mathrm{charge}}(\mathrm{t})=\min\{\mathrm{P}_B,\frac{[W_B\times SOC_{\max}-W_B(\mathrm{t-1})]\eta_c}{\Delta t}\} \tag{8}$$

$$P_{B.\mathrm{discharge}}(\mathrm{t})=\min\{\mathrm{P}_B,\frac{W_B(\mathrm{t-1})-W_B\times SOC_{\min}}{\eta_d\Delta t}\} \tag{9}$$

3. OPTIMIZATION METHOD OF ENERGY STORAGE IN AC-DC POWER DISTRIBUTION SYSTEM

3.1 Upper level optimization configuration model

The upper optimization model takes the annual investment operation and maintenance cost of BESS and the sum of the annual operation cost of the AC-DC distribution system as the optimization objective, and the decision variables are the nodes, rated power and rated capacity of BESS connected to the AC-DC distribution system. The objective function is following:

$$\min F=(C_{inv}+C_{ope}) \tag{10}$$

The constraints are shown as (11) and (12):

$$P_{B.i.\min}\le P_{B.i}\le P_{B.i.\max} \tag{11}$$

$$W_{B.i.\min}\le W_{B.i}\le W_{B.i.\max} \tag{12}$$

3.2 Lower level operation optimization model

Based on the combined data sample clustering of PVs and loads, the objective function of lower level operation optimization model is:

$$\min C_{ope}=\sum_{s=1}^{3}D(s)\times\sum_{t=1}^{T}[G_{\mathrm{buy}}(s_t)+G_{loss}(\mathrm{s}_t)+G_{PV.aban}(\mathrm{s}_t)] \tag{13}$$

At any time *t* of each scenario *s*, the following constraints should be satisfied, in addition to the constraints of (1) to (9):

(1) Nodal voltage constraint：

$$U_{i.\min}\le U_i(s_t)\le U_{i.\max} \tag{14}$$

(2) System current-carrying capacity constraint：

$$0\le I^2{}_{ij}(s_t)\le I^2{}_{ij.\max} \tag{15}$$

(3) VSC power constraint：

$$\begin{cases}\sqrt{P_{VSC}^2(s_t)+Q_{VSC}^2(s_t)}\le S_{VSC.\max}\\ P_{VSC.\min}\le P_{VSC}(s_t)\le P_{VSC.\max}\\ Q_{VSC.\min}\le Q_{VSC}(s_t)\le Q_{VSC.\max}\end{cases} \tag{16}$$

(4) Energy balance constraint for BESS in 24 hours：

$$\sum_{t=1}^{24}P_B(s_t)\times\Delta t=0 \tag{17}$$

3.3 Solving process steps

The solution flow chart of this paper is shown in Fig 1.

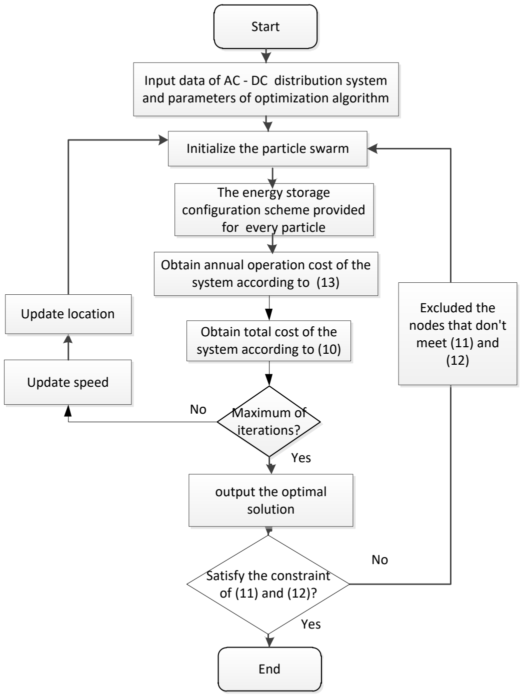

Fig.1 Flow chart of model solution

4. CASE STUDY

Case studies in this paper are modified on the basis of reference [5]. The power network topology of the cases is shown in Fig 2. The voltage level of the AC distribution subsystem and DC distribution subsystem is 10kV and ±10kV, respectively. Both VSC1 and VSC2 have a capacity of 2MVA. The loads ratios of AC distribution subsystem 1, DC distribution subsystem and AC distribution subsystem 2 are 25%, 40% and 35%, respectively.

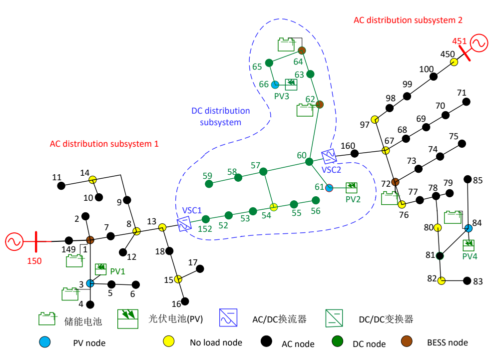

Fig.2 Topological structure of AC-DC distribution system

The AC-DC distribution system shown in the Fig 2 is transformed into the AC distribution system which is shown in Fig 3. The PVs penetration is set as 60%, and the photovoltaic curtailment penalty is set as 10 yuan/kWh. The results of BESS configuration are shown in Tab 2, and the costs are shown in Tab 3.

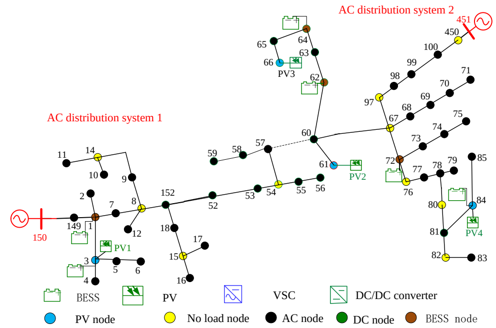

Fig. 3 Topology diagram of AC distribution system

Tab 2 BESS configuration of different distribution systems

system configuration	Nodes	power (kW)	Capacity (kWh)
AC distribution system	3	200	800
	64	200	800
	72	200	800
	84	200	800
AC-DC distribution system	64	97.90	418.30
	84	200	800

Tab 3 The annual cost of BESS configuration schemes for different distribution systems (10^4 yuan)

system configuration	Investment cost	Operation cost	Total cost
AC distribution system	97.956	1802.268	1900.224
AC-DC distribution system	37.430	1817.972	1855.402

It can be observed from Tab 2 and Tab 3 that the BESS capacity of AC distribution system is much higher than that of AC-DC distribution system under the same operating conditions.

This is because the operation state of AC distribution system cannot be adjusted flexibly according to the change of PVs and loads, and more energy storage is need to optimize the system operation. While the operation state of AC-DC distribution system can be adjusted through VSC according to the operating state of each subsystem and the whole distribution system operates cooperatively, which requires less BESS allocated.

In the previous section, only the active power of VSC is allowed to be adjusted. In actually, both active power and reactive power of VSC can be adjusted independently. Tab 4 shows the result comparison of BESS configuration under the different controllable parameters.

Tab 4 Optimal allocation results of energy storage under different controllable parameters

scenario	Nodes	Power(kV)	Capacity(kWh)
Only active power adjusted	64	97.90	418.3
	84	200	800
Active/reactive power adjusted	64	64.36	273.73
	84	200	800

From Tab 4, it can be found that BESS configuration result that considering optimizing the active power and reactive power of VSC is less than that of optimizing the active power of VSC only.

To analyze the influence of different loads distribution, three scenarios are set up shown as Tab 6, and the PVs penetration is 60%. Tab 7 shows the result of BESS configuration.

Tab 6 System loads ratio setting situation

scenario	AC distribution system 1	DC distribution system	AC distribution system 2
1	34%	20%	46%
2	25%	40%	35%
3	17%	60%	23%

Tab 7 Optimal allocation results of energy storage under different loads distributions of the system

scenario	Loads ratio	Nodes	Power (kW)	Capacity (kWh)
1	20%	84	200	800
2	40%	64	97.90	418.30
		84	200	800
3	60%	62	20.10	86.21
		64	131.81	563.26
		84	184.12	788.48

As can be seen from Tab 7, 1) the overall configuration of BESS is gradually increasing with the increase of the ratio of the loads in the DC distribution subsystem. 2) When the DC loads account for 20%, only Node 84 in AC distribution subsystem 2 is configured with BESS. While when the ratio of DC loads increases gradually, Node 64 and 62 in DC distribution subsystem are also configurated with BESS.

The main reason for this change is that, with the change of loads distribution, the power supply terminal of the whole AC-DC distribution system is transferred from AC distribution subsystem 2 to DC distribution subsystem. When the DC loads ratio continues to increase, the terminal effect of the DC distribution subsystem becomes more obvious and more BESS needs to be allocated in the DC distribution subsystem.

5. CONCLUSION

The coordination of DC distribution technology and energy storage technology is helpful to promote the safe integration and utilization of renewable energy. In this paper, a scene clustering based bi-level optimal allocation method for energy storage of AC-DC distribution system with high-penetration PVs is proposed, and conclusions can be obtained as following:

(1) Compared with AC distribution system, AC/DC distribution system can greatly improve the controllability and flexibility of the system, reduce the investment scale of energy storage, and raise the consumption level of photovoltaic energy.

(2) BESS configuration result when optimizing active power and reactive power of VSC is less than that of optimizing only active power of VSC.

(3) As the ratio of DC loads increases, the center of gravity of the system loads gradually transfers to the DC distribution subsystem, and the overall energy storage configuration power and capacity in the system also increase.

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REFERENCE

[1] Lin L, Li L, Jia L. An optimal capacity configuration method of wind/PV and energy storage co-generation system[C]. Pes General Meeting | Conference & Exposition. IEEE, 2014.

[2] Tesfahunegn S G, Ulleberg, Vie P J S, et al. Optimal shifting of Photovoltaic and loads fluctuations from fuel cell and electrolyzer to lead acid battery in a Photovoltaic/hydrogen standalone power system for improved performance and life time[J]. Journal of Power Sources, 2011, 196(23):10401-10414.

[3] Penkey P, Gaul N, Johnson B K, et al. Sizing and location identification for an electrical energy storage system in a renewable microgrid[C]// Technologies for Sustainability. IEEE, 2017:83-88.

[4] Song J, Brekken T K A, Cotilla-Sanchez E, et al. Optimal placement of energy storage and demand response in the Pacific Northwest[C]// Power & Energy Society General Meeting. IEEE, 2013:1-5.

[5] Sun Chongbo, Li Peng, Wang Chengshan, et al. Power flow calculation method for hybrid active distribution network with multiple DC links[J]. Automation of Electric Power Systems, 2015,39(21):59-65