Optimal Design of Layout and Capacity for MW PV Unit

Caixia Yang[1], Yi Su[2], Ranran Zhao[1], Yamin Wei[3]

[1]School of Electrical and Electronic Engineering, Wuhan Polytechinic University, Wuhan, Hubei, China

[2]Changjiang Engineering Survey, Planning, Design and Research Co. Ltd. Wuhan, Hubei, China

[3]Shaoxing Power Supply Company of State Grid, Shaoxing, Zhejiang, China

Keywords: photovoltaic power generation unit, unit MW installed capacity, square layout, geometric center, capacity allocation

Abstract: Taking into account in each of the photovoltaic power unit of photovoltaic power station, different length of DC bus cable corresponding to the different arrangement patterns, different influence trend of construction cost and different generating capacity relative to different installed capacity, photovoltaic array and inverter capacity need a reasonable allocation, by design analysis and engineering practice, this paper proposes the method of using a square layout, the inverter room arranged in the geometric center, the PV installed capacity more than the inverter rated capacity, reduce the amount of cable in MW photovoltaic power generation unit, reduce power consumption and improve equipment utilization rate.

1. Introduction

Photovoltaic unit is the basic organization of a photovoltaic power plant. Generally, each photovoltaic unit is equipped with a transformer and several dc-to-ac inverters[1-6]. In a practical project, the installed capacity of a photovoltaic unit is not fixed, and a photovoltaic unit can be designed according to the size of 500kWp, 1MWp, 2MWp[7].

Because photovoltaic modules need to avoid being shaded, inverters, booster transformers and matching invert cells of switch cabinet are usually arranged outside the entire photovoltaic unit, and at the same time, The invert cells of several photovoltaic units are placed on both sides of the main road in the field area, which can reduce the construction of the road in the field area and reduce the construction cost. Some studies mention that photovoltaic arrays are arranged as rectangular as possible [1,4], but the reasonable arrangement of inverters is not analyzed.

Because the area of each photovoltaic generating point unit in photovoltaic power station is too large and the amount of cable used is redundant, some researchers have paid attention to the selection of economical section of DC side converge cable in the photovoltaic power station according to line loss[8]. However, only the DC cable between the converge box and the inverter distribution box is analyzed, and all DC cables on the DC side are not analyzed.

In this paper, the layout of a photovoltaic unit with 1MW is discussed by comprehensively comparing the cable consumption of photovoltaic unit and the power transformer of photovoltaic power station. At the same time, it is proved by analysis that placing the inverter cell outside of photovoltaic power generation unit can reduce the cost of road construction in the field area, but increase the amount of cable and even increase the cost. The arrangement of the inverter cell in the geometric center of the photovoltaic unit increases the cost of road construction in the field, but reduces the cost of cable consumption and reduces the power loss on the line and improved the efficiency of photovoltaic power generation.

2. Design of photovoltaic generation unit

2.1 Adopt square layout

Photovoltaic units can be arranged into rectangular, circular or even irregular shapes according to field conditions. In a certain area, the circular circumference is the shortest, followed by the

  DOI: 10.25236/eeems.2018.062

square. When the photovoltaic unit is arranged in a circular way, the cable wiring in the photovoltaic unit may be less than that in the rectangular arrangement, but from the practical engineering point of view, the construction of the circular photovoltaic power generation unit is inconvenient. And the space between the adjacent photovoltaic units is wasted. Therefore, photovoltaic units are arranged as a regular square pattern as far as possible.

2.2 Center arrangement of Inverter Cell

The invert cell can be arranged in the geometric center of the photovoltaic unit, which is called the center arrangement (as in Fig.1), or in the periphery of the photovoltaic unit (as in Fig.2), which is called the side arrangement.

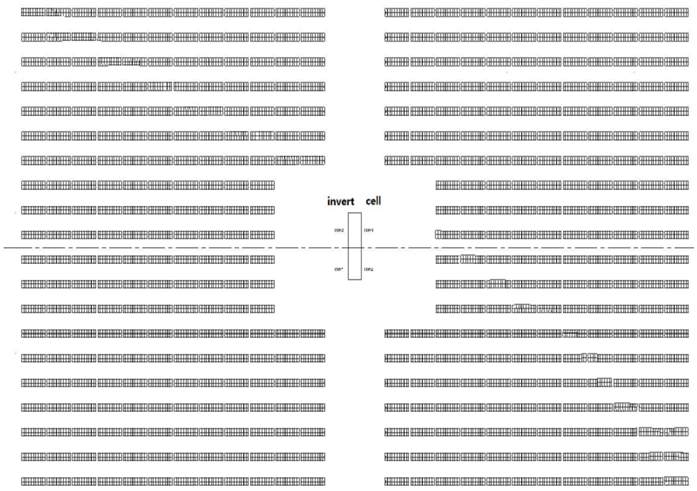

Fig.1 The center arrangement of the invert cell

Fig. 2 The side arrangement of the invert cell

According to the center arragement of Fig.1, build the route to the main road next to the invert cell. In the photovoltaic power generation unit arranged according to Fig.2, the inverter cell can be arranged directly beside the main road, thus reducing the cost of road construction. For comparison, the photovoltaic units in Fig.1 and Fig.2 are assumed to be 1MWp, with a spacing of 5m between each horizontal photovoltaic unit. It can be estimated that the layout of photovoltaic power stations in accordance with Fig.2 reduces the number of roads per MW generation unit by about 270m compared with the layout in Fig.1. The corresponding savings in road construction costs about 5000 yuan.

However, by comparing the cable usage in Fig.1 and Fig.2, assuming that all DC cables use $2\times6mm^2$ special photovoltaic cables and $1\times50mm^2$ electrical cables are used between the converge box and the invert cell, the cable consumption can be calculated as shown in Table 1.

Table1 comparison of cable consumption of MW photovoltaic units

fix up type	Cable usage(unit:m)	
	cable (2*6mm^2)	cable (1*50mm^2)
Invert cell centered	14650	1480
Invert cell sided	14650	3770

It can be seen from Table1 that the side arrangement of the invert cell mainly increases the amount of the converge cable from the converge box to the invert cell by about 2300m per MW generating unit. This raises two problems:

(1) The cost of increasing cable consumption is much higher than that of less road construction.

(2) Considering the full power operation of the photovoltaic module, the current on the converge cable is about 96A, and the resistivity of the 1×50mm^2 converge cable is 0.387Ω/km,. Therefore, the power loss per MW photovoltaic unit due to the increase of cable consumption is about 962×0.387×2.3=8203W. According to the power of 1MWp photovoltaic generation, the loss on the line is increased by about 0.82%.

Therefore, considering synthetically, if the invert cell is centered in the geometry center of photovoltaic power unit, and the economy is better and the power generation efficiency is higher.

2.3 Adopt 1MW installed capacity

There is no typical design scheme for the installed capacity of each photovoltaic unit. In this paper, the cost variation and power generation of 0.5MW, 1MW, 2MW and 3MW photovoltaic units are compared and analyzed to determine the optimal layout scale.

According to the principle that the inverters are arranged in the geometric center of photovoltaic units as far as possible, the design of 500kW, 2MW and 3MW size generating units is similar to the 1MW layout, except that the larger the capacity and the larger the area of photovoltaic units. The converge box is relatively more dispersed.

(1) Impact on costs

Although the installed capacity of units is different, the cost of modules and photovoltaic support per unit MW is basically the same, the difference mainly lies in the cost of cables and transformers per unit MW.

1) Cable cost comparison

Similarly, assuming that all DC cables use 2×6mm^2 special PV cables and use electrical cables in 1×50mm^2 between the converters and invert cell, the cable usage of different photovoltaic units and equivalent unit MW cable usage are calculated as follows:

Table 2 Statistics of cable quantity of different specifications

Specification for photovoltaic generation units	Cable usage(unit:m)			
	2×6mm^2		1×50mm^2	
	Actual usage	Equivalent unit MW usage	Actual usage	Equivalent unit MW usage
0.5MWp	6950	13900	620	1240
1MWp	14650	14650	1480	1480
2MWp	29300	14650	4820	2410
3MWp	43950	14650	10000	3333

As you can see from Table 2, the amount of DC cables used in photovoltaic units with different installed capacities is almost same, because although the capacity of photovoltaic units is different, the number of photovoltaic modules on each photovoltaic support is basically the same. Moreover, the position of each converge box is basically the same in the photovoltaic unit, so the DC cable consumption is basically the same. The difference of cable consumption between different PV units is mainly reflected in the cable consumption from converge box to invert cell.

According to the current price of 1×50mm^2 electrical cable of 30 yuan per meter, the cost of power cable of 1MWp photovoltaic unit is about 4.44×10^5 yuan, The equivalent cost of 0.5MWp, 2MWp, 3MWp photovoltaic unit per MW power cable is (1240-1480)×30=-7000yuan, (2410-1480)×30=27900yuan, (3333-1480)×30=55600yuan, respectively. That is, the larger the photovoltaic unit, the larger the cable consumption.

2) Transformer cost comparison

Different capacity booster transformers can be used in the different photovoltaic units, that is, 0.5MW, 1MW, 2MW, 3MW PV units can be used respectively as 0.5MVA, 1MVA, 1MVA, 2MVA, 3MVA transformers. According to the market price at that time, the prices of the four transformers were about 1.2×10^5yuan, 2.1×10^5yuan, 3.7×10^5yuan and 5×10^5yuan, respectively. The cost of transformers corresponding to the unit of MW photovoltaic installed capacity was 2.4×10^5yuan, 2.1×10^5yuan, 1.85×10^5yuan, 1.633×10^5yuan, respectively. That is, the larger the transformer capacity, the lower the cost per unit MW.

In a comprehensive comparison, based on the cost of 1MW photovoltaic units, the main unit MW cable costs and transformer costs of photovoltaic units of different sizes are compared as shown in the following table:

Table 3 comparison of unit MW costs with different scales

Scale	0.5MW	1MW	2MW	3MW
Cable cost(ten thousand yuan)	-0.7	44.4	+2.79	+5.56
Transformer cost (ten thousand yuan)	+3	21	-2.5	-4.67

Note: cable specification is $1\times50mm^2$.

As can be seen from Table3, the comprehensive cost difference of MW photovoltaic units on $1\times50mm^2$ cables and transformers is very small, and the economical efficiency between them is same, among which the 0.5MW scale photovoltaic units have the highest cost per unit MW. The main reason is that it can not reflect the scale advantage of photovoltaic power plant layout.

(2) Impact on electricity generation

1) Line loss comparison

The maximum output current of photovoltaic module is about 8A and the current on the converge cable is about 96A according to the full power operation of photovoltaic module. Because the consumption of primary DC cable of unit MW photovoltaic power unit is equal, the corresponding line loss is equal, and the main difference of line loss is reflected on the second grade converge cable.

According to the 0.387Ω/km resistivity calculation of $1\times50mm^2$ convergent cable and the statistics in Table2, the power losses on the converge cable per unit MW capacity of photovoltaic power generation units of different sizes are as follows:

0.5MW scale:

962×0.387×1.24=4422W

1MW scale:

962×0.387×1.48=5278W

2MW scale:

962×0.387×2.41=8596W

3MW scale:

962×0.387×3.33=11877W

It can be seen that the larger the PV generating unit is, the more the converge cable is, so the line loss is larger. The increase of line loss reduces the energy conversion efficiency of photovoltaic power station. From the point of view of improving the efficiency of solar energy utilization, the use of smaller photovoltaic units is more conducive to increase the power generation of photovoltaic power station. Among them, the difference between 0.5MW and 1MW scale secondary DC bus losses is small, and that of 1MW scale generation units is about 0.33% less than that of 2MW scale generation units.

2) Effect comparison of Maximum Power Point Tracking(MPPT) for Photovoltaic DC-to-AC Inverter

The photovoltaic converter adopts the maximum power point tracking control, which is essentially a self-optimization process, that is, the photovoltaic converter continuously adjusts the working point voltage to make it close to the peak power point. When the output voltage of multiple groups of PV modules on the input side of the inverter is not same, the operating point voltage of the converter can not match the maximum power output point of all the input side PV module strings at the same time, thus reducing the efficiency of the converter.

Compared with the photovoltaic units of 0.5MW, 1MW, 2MW and 3MW, the shortest length of the converters is 21m, and the longest is 45m, 54m, 98m and 145m respectively. According to the specification of converge cable of $1\times50mm^2$, the resistivity is 0.387Ω/km meter, and the maximum voltage drop is about 1.7V, 2V,3.6V, 5.4V respectively. It can be seen that the larger the photovoltaic generation unit is, the greater the voltage difference between the converge box and the inverter port is, and the more photovoltaic modules are difficult to work near the maximum power tracking point, thus affecting the total generating capacity of the power station.

Therefore, from the point of view of MPPT tracking control, the smaller the photovoltaic power generation unit is, the more favorable it is to increase the power generation capacity per unit MW photovoltaic unit.

In conclusion, the smaller the photovoltaic unit is, the more favorable it is to increase the power generation of the unit MW photovoltaic module. However, the engineering cost of 0.5MW photovoltaic unit is too high. Therefore, the photovoltaic unit using 1MW can achieve a good balance between electricity generation and project cost.

2.4 Photovoltaic module capacity overmatch

The typical configuration of photovoltaic module and inverter in photovoltaic power station is to match the two power, that is, one 500kW inverter is configured for each 500kWp.

However, from the analysis of actual operation condition, the photovoltaic module with 1MWp installed capacity can not reach the rated output power of 1MW because of the limitation of actual operation condition and photovoltaic resource condition. The inverter operates most of the time under the condition of less than rated power. For example, the lower the PV resource, the smaller the output power of PV module, and the lower the actual capacity of inverter.

According to the specification of the inverter, the input power of the photovoltaic inverter is allowed to be greater than its rated power. In addition, according to the efficiency curve of the inverter (Fig.3), when the output power of the photovoltaic inverter exceeds 50%, the efficiency of the photovoltaic inverter changes little and is basically stable by the same value. That is to say, increasing the installed capacity of the PV module in the inverter input can not reduce the efficiency of the inverter. As a result, each inverter can access photovoltaic modules greater than its rated power. Even if the PV module is not rated due to efficiency constraints, the total output power of the inverter is greater than when only 500kWp photovoltaic modules are configured. Output power without damaging the inverter.

The installed capacity of the PV module can be accessed by the inverter according to the light resource condition and the field environment. When the maximum output power of PV module is less than the rated power, the power of PV module connected to the output side of inverter can be increased. For example, photovoltaic modules can be prepared in proportion to the rated capacity of the inverter at 1.2 times or higher; If the local optical resources are well and the maximum output power of the photovoltaic module is high, the overmatch of the photovoltaic module on the input side of the inverter can be reduced (for example, according to the ratio of the PV module capacity: the rated capacity of the inverter equals to 1.05: 1), to avoid the actual input power exceeds the inverter safety limit.

If under the condition of 500kW inverter configured 550kW photovoltaic module to calculate, the ratio of the installed capacity of PV module to the rated capacity of the inverter is 1.1:1, 20 inverters, which can be connected to the 11MWp PV module by using the installed capacity of the 550kW PV module configured with the 500kW inverter and the ratio of the installed capacity of the PV module to the rated capacity of the inverter. According to the conventional arrangement, 11MWp photovoltaic modules need to be equipped with 22 inverters and 11 booster transformers. Therefore, the design of the supermatched PV module of the inverter saves two inverters, a transformer and its matching switchgear, etc. The cost is reduced by about 2 million.

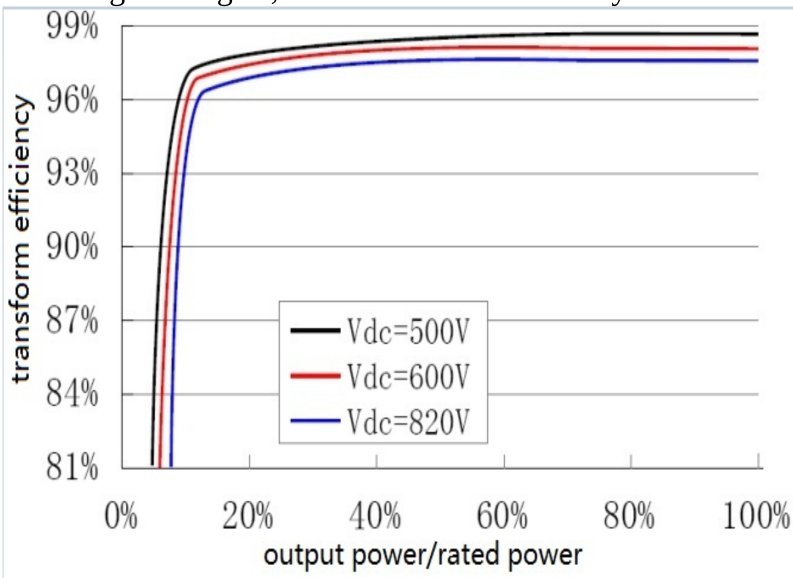

Fig.3 Efficiency curve of photovoltaic inverter

3. Application example

According to the maximum design concept of MW photovoltaic power generation unit, a certain 10MW grid-connected photovoltaic power generation project in Golmud is optimized according to the field conditions in the design process.

Because the project site is flat and the planning scope is relatively neat, the power station has a total of 10 photovoltaic units per 1MW, each building an invert cell, two 500kW photovoltaic inverters are installed in each inverter room, and the arrangement of three photovoltaic units is shown in Fig.4. The photovoltaic units are arranged in turn, the cell are placed in the geometric center of each photovoltaic unit, and the three inverters are connected through the road and the main road in the field area.

Considering that the light conditions in Qinghai Province are well and that the output power of the photovoltaic module is close to its nominal rated power, the actual installed capacity of each 1MW photovoltaic unit is set to 1.1MWp, That is to say, the output power of photovoltaic module is 1.1MW. The ratio of the installed capacity of the PV module to the rated output power of the inverter is 1.1:1, which is larger than the rated input power of the inverter and less than the maximum allowable input power of the inverter.

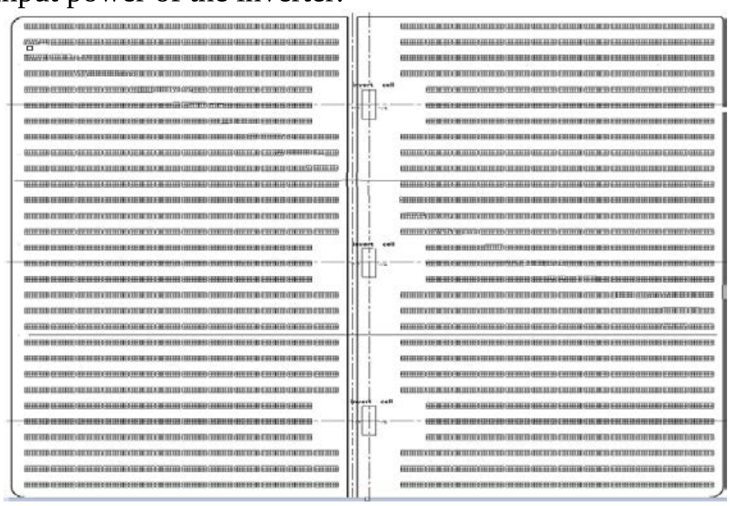

Fig.4 three sets of photovoltaic unit layout

The application of maximum power generation design of MW photovoltaic unit in a certain 10MW photovoltaic power station in Geermu saves about 2million yuan of direct investment in the project, improves the efficiency of photovoltaic power generation about 1.5%, and finally reduces the cost of photovoltaic power generation. The efficiency of photovoltaic power generation is improved. Based on the actual data of power generation, the cumulative economic benefits of this innovative design for 25 years can be over 6 million yuan.

4. Conclusion

Photovoltaic units are arranged as square as possible, and the inverter should be arranged in the geometric center of the photovoltaic unit as far as possible. By this arrangement, the total cable consumption is minimized, the line loss is reduced, and the energy conversion efficiency of the photovoltaic power station is improved. In addition, it makes the photovoltaic module power at the input end of a single inverter configured as 1.1 times of the rated power of the inverter, and the output power of the inverter can be improved by making full use of the characteristics of the inverter which can access the photovoltaic module exceeding the rated power.

For the first time, four main factors affecting the efficiency of photovoltaic power generation are analyzed systematically in this study. The successful application of the results has important guiding significance for the rational planning of photovoltaic power generation units. It provides a solid technical support for the scale construction of photovoltaic power station.

References

[1] Xu Yongbang, Su Xingfeng, Xia Deng, et al. An arrangement method of ground Photovoltaic Electric Field Array [P]: CN200910182120.7,2009-12-9.

[2] Liao E, Li Shihua. Discussion on Design method of Large-Scale Photovoltaic Grid-connected Power Station[C] .2011 National Annual meeting of Wind Power Engineering Information Network, Sanya, 2011: 182-191.

[3] Zhang Z, Lv Dan, he J. Design and layout of a photovoltaic power station [J] .Solar Energy, 2014, (10): 24-26.

[4] Li Runsheng, Hu Qing, Song Yang, et al. Photovoltaic square array [P]: CN201320417574.X, 2014-3-5.

[5] Wang Chao. Study on cable laying cost in photovoltaic area based on converge box arrangement[J] .Science and Technology Innovation and Application, 2014,(19): 182.

[6] Xie Dan, Ju Jian, Yu Miao, et al.Discussion on the pattern of photovoltaic cell array arrangement[J] .Solar Energy, 2013,(23): 28-31.

[7] Yang Jian, Guo Zhi, Yang Yudong. Integrated Unit system of two MW Inverter for Photovoltaic Power Station[P]: CN201320348579.1, 2013-11-27.

[8] Zhang Yanchang, Shi Wei. Selection of DC Converge Cable for Photovoltaic Power Station[J] .Electric Power Construction, 2014N35(2):113-116.