Optimization Analysis of Distributed Photovoltaic Generation System Design Based on Substituting 50 kW Inverter for 100 kW Inverter

Yulu Wei[1, 2, 3, 4], Kaige Fu[5]

[1]Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering, Construction Group Co., Ltd, Xi'an 710075, China

[2]Shaanxi Provincial Land Consolidation Engineering Technology Research Center, Xi'an 710075, China

[3]Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Natural Resources of China, Xi'an 710075, China

[4]Shaanxi Provincial Land Engineering Construction Group Co, Ltd, Xi'an 710075, China

[5]China Jikan Research Institute of Engineering Investigation and Design Co., Ltd, Xi 'an 710000, China

Abstract

Promoting the whole-county (city or district) construction of rooftop distributed photovoltaic generation is an important part in realizing the two major national strategies of "carbon peak, carbon neutrality" and rural revitalization. In this paper, a distributed photovoltaic generation system design scheme based on substituting 50 kW inverter for 100 kW inverter is proposed for industrial and commercial rooftop photovoltaic projects. Through detailed comparative analysis, it is concluded that the design scheme entailing the use of 50 kW inverters is more economic and cost-effective than using 100 kW inverter.

Keywords

Distributed Photovoltaic Generation; Cluster Inverter; AC Cable; Cost Comparative Analysis.

1. Introduction

On June 20, 2021, the Comprehensive Department of the National Energy Administration officially issued the "Notice on Submitting the Pilot program of roof distributed photovoltaic Development in the whole county (city or district)", which intends to organize and carry out the pilot work of roof distributed photovoltaic development in the whole county (city or district).The notice clearly pointed out that the total area of the roof of the party and government buildings can be installed with photovoltaic power generation ratio of not less than 50%; Schools, hospitals, village committees and other public buildings roof total area can be installed photovoltaic power generation ratio of not less than 40%; The total area of the roof of the industrial and commercial plant can be installed with photovoltaic power generation ratio of not less than 30%; The total area of the roof of rural residents can install photovoltaic power generation ratio of not less than 20%.To carry out the whole county (city or district) to promote the construction of roof distributed photovoltaic, is conducive to the integration of resources to achieve intensive development, is conducive to reducing the peak load of power, is conducive to saving and optimizing the investment of distribution network, is conducive to guiding residents' green energy consumption, is an important measure to achieve "carbon peak, carbon neutrality" and rural revitalization of the two major national strategies.

2. Traditional Scheme

The total installed capacity of an industrial and commercial rooftop photovoltaic power generation project is 110 kWp, using 200 pieces of 550 Wp mono-crystalline silicon photovoltaic modules, equipped with a 100 kW series inverter, AC cable using copper core crosslinked polyethylene insulated steel tape armoury PVC sheathed power cable YJV22-0.6/1.0-3×70+1×35 mm^2, The cable is 100 m long and uses 380 V low voltage with a parallel point connected to the grid.The main electrical wiring of the scheme is shown in Figure 1.

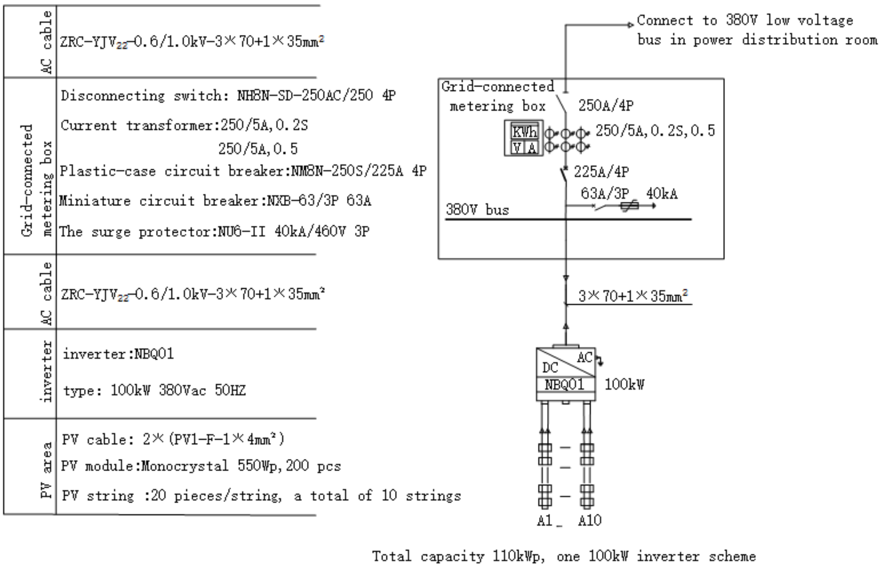

Figure 1. 110kWp photovoltaic grid-connected electrical main wiring diagram under the conventional scheme

3. Optimization Scheme

In the optimization scheme, two 50kW series inverters are used to replace one 100kW inverter, and the AC cable is changed to copper core crosslinked polyethylene insulated steel tape armored PVC sheathing power cable YJV22-0.6/1.0-3×25+1×16 mm2, with a single cable length of 100 m. The same 380 V low voltage single point grid connection.The main electrical wiring of the optimization scheme is shown in Figure 2.

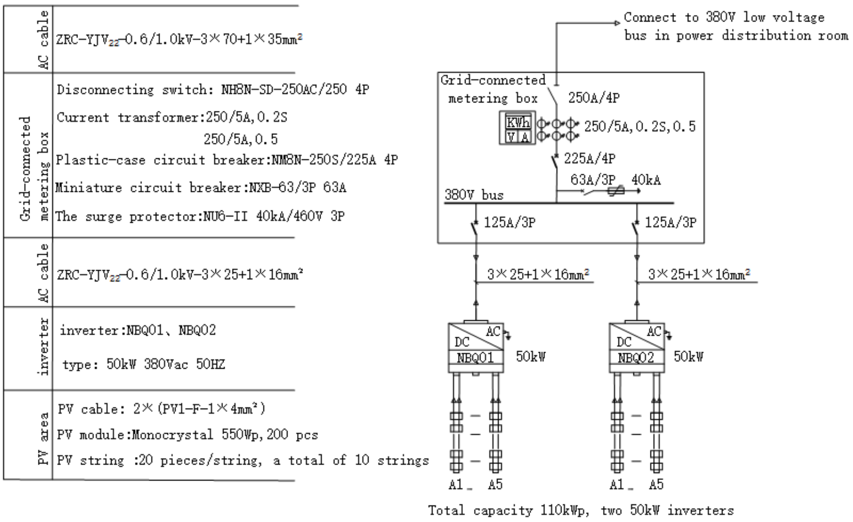

Figure 2. 110kWp photovoltaic grid-connected electrical main wiring diagram under the optimized scheme

4. Cost Comparison

The main equipment configuration list and cost comparative analysis of the conventional scheme and the optimized scheme are shown in Table 1.The cost of photovoltaic modules and inverters is basically unchanged, and the cost of low-voltage distribution cabinets and manual installation has increased slightly, but the cost of AC cables has decreased greatly, which is the key factor to reduce the total cost.After the optimization of the program, the total cost can be reduced by 2712 yuan, which is equivalent to about 2.5 fen/Wp.Therefore, for industrial and commercial projects with dispersed roofs, complex roofs and relatively close distribution rooms, the selection of 50 kW small inverters is also a more economical and practical scheme.

Table 1. General scheme and optimization scheme main equipment configuration list and cost comparative analysis table

NO.	Main equipment	Conventional scheme equipment selection	Optimization scheme equipment selection	Optimization program saves cost/yuan
1	Photovoltaic module	220 module,550Wp	220 module,550Wp	0
2	inverter	110kW,one	50kW,two	0
3	AC cable (Inverter output to low-voltage grid-connected metering box)	100m YJV$_{22}$-0.6/1.0-3×70+1×35mm^2	2×100m YJV$_{22}$-0.6/1.0-3×25+1×16mm^2	-3112
4	Low voltage grid-connected metering box (including switch)	One 225A circuit breaker	two 125A circuit breaker	+300
5	Manual installation	1 person,1h	1 person,2h	+100
6	BOS total			-2712

5. Key Equipment Selection

As can be seen from Table 1, the key to reducing costs is the selection of AC cables.The selection of power cable section is analyzed below.The calculated current of the electrical equipment group is [1] :

$$I_c = \frac{S_c}{\sqrt{3}U_r} \tag{1}$$

Ic is the calculation current, A; Sc is the apparent power, kVA; Ur is the rated voltage of the equipment (line voltage), kV.

According to the parameters provided by the selected inverter manufacturer, the maximum output apparent power of the 50 kW inverter is 55 kVA, the rated output power is 50 kW, and the rated output voltage is AC 380 V, then the calculated current (maximum output current) of the inverter is 83.6A and the power factor is 0.91.

5.1. Select by Continuous Allowable Current

The calculation formula of the allowable load flowmeter for the cable laid in the air and soil is [2] :

$$KI_N \geq I_g \tag{2}$$

Where I_g is the calculated working current, A; I_N is the rated carrying capacity of the cable under standard laying conditions, A; K is the comprehensive correction factor under different laying conditions.Single laying in the air $K=K_t$, When multiple wires are laid in the air $K=K_tK_1$, When piping is laid in the air $K=K_tK_2$, When laying single roots in soil $K=K_tK_3$, When multiple roots are laid in the soil $K=K_tK_3K_4$. Where, K_t is the correction coefficient of ambient temperature; K_1 is the correction factor of the current carrying capacity of the parallel laying cable in the air, or the correction factor of the multi-layer parallel laying cable on the bridge; K_2 is the correction factor of the carrying current when the pipe is laid in the air, which is 0.9 when the voltage is 10 kV or below, the cross section is 95 mm^2 or below, and 0.85 when the cross section is 120~185 mm^2. K_3 is the correction coefficient of the direct buried cable due to different soil thermal resistance; K_4 correction factor for multiple parallel direct buried laying.

The low-voltage AC cable between the inverter and the grid-connected cabinet of this power station is laid by ladder, which is laid in 1 layer. Check GB 50217-2018 "Design Standard for Electric Power Engineering Cables", and the correction coefficient [3] when laying in ladder is Kt =1 (ambient temperature 40 ℃), K_1=0.8. For others, see Table 2 and Table 3.Therefore, the comprehensive correction factor K under the ladder laying mode is 0.8.

Table 2. Current carrying correction factor of cables 10 kV and below at different ambient temperatures

Laying position		**In the air**				**In soil**			
Ambient temperature/℃		30	35	40	45	20	25	30	35
Maximum operating temperature of the cable conductor/℃	60	1.22	1.11	1.0	0.86	1.07	1.0	0.93	0.85
	65	1.18	1.09	1.0	0.89	1.06	1.0	0.94	0.87
	70	1.15	1.08	1.0	0.91	1.05	1.0	0.94	0.88
	80	1.11	1.06	1.0	0.93	1.04	1.0	0.95	0.90
	90	1.09	1.05	1.0	0.94	1.04	1.0	0.96	0.92

Table 3. The correction coefficient of multi-layer parallel cable carrying capacity is configured on the cable bridge without spacing

Number of overlapping cable layers		**1**	**2**	**3**	**4**
Type of bridge	**Ladder stand**	0.8	0.65	0.55	0.5
	tray	0.7	0.55	0.50	0.45

Note: The number of horizontal parallel cables is not less than 7.

Table 4. 1 ~ 3 kV crosslinked polyethylene insulated cable is allowed to carry current when laying in the air

item		**Cable allowable current carrying capacity /A**									
Cable core number		**three-core**		**Single core**							
Single-core cable arrangement				**Pin font**				**Horizontal form**			
Metal shield ground point				**unilateral**		**Two sides**		**unilateral**		**Two sides**	
Cable core material		**Al**	**Cu**	**Al**	**Cu**	**Al**	**Cu**	**Al**	**Cu**	**Al**	**Cu**
Cable core cross-sectional area /mm²	**25**	91	118	100	132	100	132	114	150	114	150
	35	114	150	127	164	127	164	146	182	141	178
	50	146	182	155	196	155	196	173	228	168	209
	70	178	228	196	255	196	251	228	292	214	264
Ambient temperature/℃		40									
Maximum operating temperature of the cable conductor/℃		90									

Note: The center distance between horizontal cables is 2 times the outer diameter of the cables.

By referring to the "Allowable current carrying Table (see Table 4) for 1 to 3 kV cross-linked polyethylene insulated cable laid in the air" in the "Quick Reference Manual for Common Data of Wire and Cable", it can be seen that the cable carrying current of YJV$_{22}$-0.6/1-3×25+1×16 mm^2 is 118 A (laid in the air at an ambient temperature of 40 ℃). The current carrying capacity corrected by the comprehensive correction factor K is 94.4A, which is greater than the calculated working current of the inverter (83.6A). Therefore, after calculation and comparison, the low-voltage AC cable from the inverter to the grid-connected cabinet is selected as YJV$_{22}$-0.6/1.0-3×25+1×16 mm^2 cable, which can meet the requirements of the allowable current carrying capacity of the cable.

5.2. Check by Voltage Loss

According to GB 19964-2012 "Technical Regulations for Photovoltaic Power Station Access to the Power System" [4], after the photovoltaic power station is connected, the voltage deviation of the connected public connection point should meet the requirements of GB/T 12325.According to the provisions of GB/T 12325-2008 "Power quality Supply Voltage Deviation" [5], the sum of absolute positive and negative deviation of 35 kV and above supply voltage shall not exceed 10% of the nominal voltage; The deviation of three-phase power supply voltage of 20 kV and below is ±7% of the nominal voltage; 220 V single-phase supply voltage deviation is +7%,-10% of the nominal voltage.The cable voltage drop of this project is checked by the AC side voltage drop ΔU% is less than 5%.

5.2.1. Calculation Formula

According to the "Electrical Primary Part of the Electrical Design Manual of Power Engineering" [6], the voltage drop calculation formula of the three-phase AC cable line is as follows:

$$\Delta U\% = \frac{173}{U} I_g L(r\cos\varphi + x\sin\varphi) \tag{3}$$

Where I_{g} is the calculated working current, A; U is the line operating voltage, three phase is the line voltage, V; L is the length of the line, km; r is the cable unit length resistance, Ω/km; x is the cable unit length reactance, Ω/km; cosφ is the power factor.

After the line is energized, the wire will produce temperature rise, which is closely related to the size of the passing current (that is, the load rate). Due to the different power supply objects, the load rate in various lines is also different, so the actual operating temperature of the wire core is often different. When reasonably calculating the voltage loss of the line, the actual operating temperature of the wire should be obtained first [3]. The actual core temperature in the project is: 6~35 kV overhead line θ=55 ℃; 380 V overhead line θ=60 ℃; 35 kV crosslinked polyethylene insulated power cable θ=75 ℃; 1~10 kV crosslinked polyethylene insulated power cable θ=80 ℃; 1 kV PVC insulated and sheathed power cable θ=60 ℃.

According to the "1 kV crosslinked polyethylene insulated power cable for three-phase 380 V system voltage loss table (see Table 5)" in the third edition of the "Industrial and Civil Distribution Design Manual", it can be obtained that the resistance of the copper cable with a cross-section of 25 mm^2 is 0.870 Ω/km and the reactance is 0.082 Ω/km when the working temperature of the online core is 80 ℃.

Table 5. Crosslinked polyethylene insulated power cables are used for voltage loss in three-phase 380V systems

Cross section/mm^2		**resistance θ=80℃/(Ω/km)**	**Inductive reactance/(Ω/km)**	**Voltage loss/[%/(A.km)]**					
				cosφ					
				0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**
copper	4	5.332	0.097	1.253	1.494	1.733	1.971	2.207	2.430
	6	3.554	0.092	0.846	1.006	1.321	1.321	1.476	1.620
	10	2.175	0.085	0.529	0.626	0.816	0.816	0.909	0.991
	16	1.359	0.082	0.343	0.402	0.518	0.518	0.574	0.619
	25	0.87	0.082	0.231	0.268	0.304	0.340	0.373	0.397

According to equation (3), the maximum transmission distance of 25 mm^2 copper cable under different voltage drops is shown in Table 6 when the rated output power of the inverter is 50 kW, the calculated current is 83.6A and the power factor is 0.91, and when the rated output power of the inverter is 50 kW, the calculated current is 76 A and the power factor is 1.

Table 6. The maximum transmission distance of 25 mm^2 copper cable is obtained from formula (3)

Cable allowed voltage drop			**2%**	**3%**	**4%**	**5%**
Maximum transmission distance/m	cos φ	0.91	63.6	95.5	127.3	159.1
		1.0	66.4	99.7	132.9	166.1

5.2.2. Calculation Table

According to the "Industrial and civil distribution Design Manual" 3rd edition of Table 9-63 "line voltage loss calculation formula", can be directly based on the three-phase line cross section and load power factor table to obtain per kW·km (load moment) or A·km (current moment) voltage loss percentage, and then according to formula (4) or (5) to find the total voltage loss:

$$\Delta u\% = \Delta u_a\% Il \tag{4}$$

$$\Delta u\% = \Delta u_p\% Pl \tag{5}$$

Where, $\Delta u\%$ is the percentage of line voltage loss, %; $\Delta u_a\%$ is the percentage of voltage loss per 1 A·km of three-phase line, %/ (A·km); $\Delta u_p\%$ is the percentage of voltage loss per 1 kW·km of the three-phase line, %/ (kW·km); I is the load calculation current, A; P is active load, kW; l is the length of the line, km.

According to the "1 kV crosslinked polyethylene insulated Power cable for Use in three-phase 380 V System Voltage loss Table" in the 3rd edition of the Industrial and Civil Distribution Design Manual, the voltage loss of 25 mm^2 copper cable at A power factor of 0.9 is 0.373[%/(A·km)]. When the power factor is 1.0, the voltage loss is 0.397[%/(A·km)]. According to Formula (4), the maximum transmission distance of a copper cable with a cross-section of 25 mm^2 under different voltage drops can be obtained, as shown in Table 7.

Table 7. The maximum transmission distance of 25 mm^2 copper cable is obtained from formula (4)

Cable allowed voltage drop			**2%**	**3%**	**4%**	**5%**
Maximum transmission distance/m	cos φ	0.9	64.1	96.2	128.3	160.3
		1.0	66.3	99.4	132.6	165.7

5.2.3. Brief Summary

According to the calculation formula and calculation table, when the AC side cable pressure drop $\Delta U\%$ is less than 5%, the maximum transmission distance of the 25 mm^2 copper cable is about 160 m, which is larger than the actual cable length of the project (100 m). Therefore, the copper cable with a section of 25 mm^2 is selected for the 50 kW inverter to meet the requirements of relevant design specifications.

6. Comparative Analysis of Key Equipment Cost

In the optimization scheme, the 50 kW inverter chooses a copper cable with a cross-section of 25 mm^2 or a copper cable with a cross-section of 35 mm^2, which has a great impact on the system cost. Query the price of YJV$_{22}$-0.6/1-3×25/35/70 mm2 cable in the 6th issue of "Shaanxi Engineering Cost Information" in 2022. The comparison of price and single watt cost of Western Cable Co., Ltd. is shown in Table 8, and the comparison of price and single watt cost of Shaanxi Qinli Power Cable Manufacturing Co., Ltd. is shown in Table 9.

Table 8. Western cable Co., LTD. Cable price and single watt cost comparison table

NO.	Inverter power/kW	Cable selection/mm²	Cable price/(yuan/m)	100m Per watt cost/(fen/W)	100m Difference value/(fen/W)	150m Per watt cost/(fen/W)	150m Difference value/(fen/W)
1	100	70	414.68	41.47	0.00	62.20	0.00
2	50	25	187.99	37.59	-3.88	56.39	-5.81
3	50	35	246.26	49.25	+7.78	73.88	+11.68

Table 9. Shaanxi Qinli Power cable Manufacturing Co., LTD. Cable price and single watt cost comparison table

NO.	Inverter power/kW	Cable selection/mm²	Cable price/(yuan/m)	100m Per watt cost/(fen/W)	100m Difference value/(fen/W)	150m Per watt cost/(fen/W)	150m Difference value/(fen/W)
1	100	70	295.54	29.55	0.00	44.33	0.00
2	50	25	132.21	26.46	-3.09	39.66	-4.67
3	50	35	157.89	31.58	+2.03	47.37	+3.04

As can be seen from Table 8 and Table 9, the use of 50 kW inverter corresponding to the selection of 25 mm^2 cable, compared with the use of 100 kW inverter corresponding to the selection of 70 mm^2 cable, the single watt cost per 100 m length cable will be reduced by 3.88 fen /W or 3.09 fen /W. The single watt cost per 150 m length cable will be reduced by 5.81 fen /W or 4.67 fen /W; Using a 50 kW inverter corresponding to the selection of 35 mm2 cable, compared with a 100 kW inverter corresponding to the selection of 70 mm2 cable, the single watt cost per 100 m length of cable will increase by 7.78 fen /W or 2.03 fen /W. The cost of a single watt per 150 m length cable will increase by 11.68 fen /W or 3.04 fen /W. Therefore, in the optimization scheme, only the selection of 50 kW inverter and the selection of copper cable with a cross-section of 25 mm^2 can make the system cost lower than the conventional scheme system.

7. Conclusion

In the context of "3060", with the implementation of "the whole county to promote", industrial and commercial and household photovoltaic will usher in explosive growth during the "14th Five-Year Plan" period. For industrial and commercial photovoltaic projects with dispersed roofs, complex roofs and close distribution rooms, the selection of 50 kW inverters will have more cost advantages than the selection of 100 kW inverters, and the cost performance is higher.

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