DSO'S CHALLENGES WITH THE POVERTY ALLEVIATION PV POWER DEVELOPMENT IN CHINA

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ABSTRACT

In China, the national support policy for poverty alleviation based on photovoltaic power development (PAPV) began in 2014. Targeting pervert families and villages in China's developing provinces, it has rapidly promoted distributed PV power development in rural distribution networks. This paper presents the development of PAPV policy, the construction and financial modes of PAPV projects. PAPV development in the Baoji supply area as a real-world case is presented in detail. PAPV development largely change the role and business of local DSOs, and the planning and operation of local networks. Challenges and possible solutions for DSOs are discussed.

PAPV POLICY DEVELOPMENT

China's PAPV policy conforms to both the national renewable energy development strategy and the national poverty alleviation strategy. It is formulated by the State Council Leading Group Office of Poverty Alleviation and Development, the National Development and Reform Commission, the National Energy Administration (NEA), and supported by the Ministry of Finance, the Ministry of Land and Resources and local governments. In 2014 and early 2015, the NEA initiated the work of PAPV pilot projects. In 2016, the implementation of PAPV projects began across the developing provinces in China. From 2014 to 2018, relevant national departments issued a series of PAPV policies (see Table 1).

Table 1 Development of PAPV Policy

Year	Policies
2014-2015	PAPV pilot project initiative
2016.03	National PAPV implement strategy
2016.10	First plan 516MW of PAPV projects
2017.12	Land-use policy for PAPV projects
	Management for the income share of village PAPV station
	First national plan 419MW of PAPV projects in 2016-2020
2018.03	PAPV allowance policy
	Management for PAPV station construction and operation

In China, criteria for poverty household varies from time to time. In 2017, among the rural population, while the average annual income is 5,500 RMB per-capita, that of poverty household is less than 3,000 RMB per-capita and the poverty population was about 30.46 million, 3% of the rural population. In addition, each province sets criteria of poverty village according to local economic development, such as relatively high poverty population (e.g. more than 5%), low per-capita income (less than 60%) and no village collective economic income. National PAPV policy aims especially at poverty households in poverty villages, and gives priority to the poverty in deeply poverty areas and those with weak labour capacity.

There are three types of construction mode shown in Table 2. PV capacity allocates a poverty household, with an average 5 kW and a maximum 7 kW. A single village PAPV station should be no larger than 500 kW. A multi-village cluster PAPV station should not exceed 6000 kW. All PAPV stations connect to MV or LV networks. Requirements of PAPV project includes that the illumination time of PAPV station is more than 1100 hours.

Table 2 Construction Modes of PAPV Projects

Mode	U_N (kV)	P_N (kW)
Household	0.22/0.38	≤ 7
Village	0.38, 10	100~500
Multi-Village Cluster	10	≤6000

Investment Financing and Income Sharing

Government, banks and customers can jointly invest PAPV projects. Since 2018, enterprise is not allowed to invest PAPV project. Property rights of PAPV stations invested by government funds belong to village collectives, and all incomes are used to alleviate poverty. According to PA policy, national or provincial government subside PAPV project by the allowance of PAPV generation. Besides, PAPV stations uses part of electricity generation allowance and sales income to repay loans. PAPV project should ensure that each PAPV household receives an annual income more than 3,000 RMB.

For a household PAPV station, the property right and all the income belong to the household.

For small-scale PAPV stations, village may use village collectives' non-farming land to build, village collectives own the assets, and both village collectives and targeted poverty households share the income in a proper proportion. Most of the income should be directly to the targeted poverty households and the rest is to public poverty alleviation fund of the village collectives. Generally, the income of poverty households should account for more than 60% of the total.

For large-scale PAPV stations, they are often built by joint ventures and the assets belong to the main entities of the investment financing and the investment enterprises,

and the income shared by them. To the targeted poverty households, the entity of investment and financing should participate in the investment and operation, quantify the share of income according to the share of investment, and distribute the asset income monthly (or quarterly).

Status of PAPV Development

Before 2015, China focused PV power development on very large-scale centralized type in less populated regions. Since 2016, China initiated distributed PV power (D-PV) development and got significant results in a short period, PAPV power has become a unique part of D-PV development in China. The installed capacity of PV power, D-PV power, PAPV power in 2014-2018 are shown in Table 3. It shows the proportion of D-PV increases from 12% to 28% and PAPV is about 20% of the D-PV power.

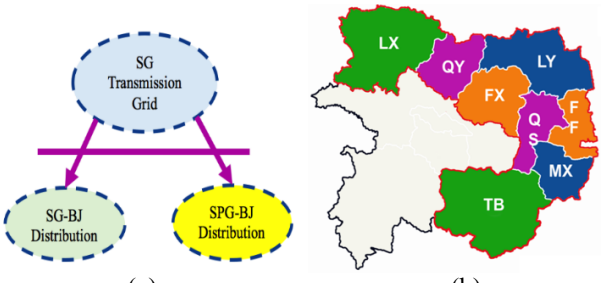
Table 3 PV, D-PV and PAPV Capacity in 2015-2018

Year	2015	2016	2017	2018
∑PAPV (GW)	/	/	5.53	>10.0
Δ D-PV (GW)	1.39	4.23	19.44	17.1
∑D-PV (GW)	6.06	10.32	29.66	46.8
∑D-PV/∑PV %	12	13	23	28
∑PV (GW)	49.3	77.4	130.3	164.7

PAPV projects mainly aim at rural areas in the developing regions of China. Most PAPV stations connect to the weakest MV/LV distribution networks in China, opening a very unique way for the distributed PV power development. In the central and eastern China where land resources are scarce, village PAPV stations (including household) are the major models. In the western and central regions where land resources are abundant, multi-village cluster PAPV stations are options.

The above briefly introduces the national PAPV policy development and the PAPV power installation status. The following presents the PAPV development in a rural supply area, the impact of on the distribution business, the distribution network planning and operation, the main challenges for DSOs.

PAPV PROJECTS IN SPG-BJ SUPPLY AREA



(a) (b)

Figure 1 SPG-BJ power supply mode and area

Power supply of the rural area in Baoji administration region of Shaanxi Province in China is shared by the DSO of State Grid Corporation (SG) and the DSO of Shaanxi Regional Electric Power Group Co., Ltd (SPG)[1], namely SG-BJ and SPG-BJ respectively. SG takes also charge of the transmission business in Baoji area. Figure 1(a) and 1(b) show the mode and the eight counties of SPG-BJ power supply. Within an area about 11,414 km^2, the voltage level of SPG-BJ distribution network is 35/10/0.4kV, connected to the 110/330 kV of SG grid. SPG-BJ provide distribution business and sales services through independent distribution networks, to 0.67 million customers, of 2.25 million people, almost all of the agricultural residents in the service area.

PAPV projects in SPG-BJ Supply Area

Five of the eight counties are the national poverty counties, therefore the priority target of PAPV projects. With the support of the national PAPV policy, the installation of distributed PV stations in SPG-BJ supply area has increased dramatically in recent years, and PAPV projects have significant initial results. It is expected that during 2016-2020, an annual capacity of 6 MW may integrate to SPG-BJ distribution network.

By Oct. 2018, 597 PAPV projects have been built in SPG-BJ supply area, with a total capacity of 23.7 MW. Among them, 264 projects are national PAPV projects and the rest are provincial self-invested ones. Table 4 shows the statistic of PAPV projects in SPG-BJ's counties. It shows the average ratio of peak-load vs. valley-load is as large as 6. Although the total PAPV capacity is only about 4.6% of the area's peak load but about 16.0% the valley load, there appears significant impacts on planning and operation of the distribution networks. Figure 2 shows daily generation curves of a village PAPV station and a village cluster one. PAPV power generation is concentrated in the period of 10:00~16:00.

Table 4 PAPV Stations in SPG-BJ Supply Area

County	Area (km^2)	Pop. (*10^4)	Load (MW)		PAPV stations	
			Max	Min	No.	∑P (MW)
FX	1179	51	98	13	107	1.1
FF	751	46	134	24	84	1.3
LX	2418	25	41	5	86	4.7
MX	863	30	145	22	85	0.8
QS	855	46	97	24	52	6.5
QY	959	13	81	5	24	7.0
TB	2780	5	29	2	153	1.1
LY	1606	9	46	6	6	1.2
Total	11411	225	520	148	597	23.7

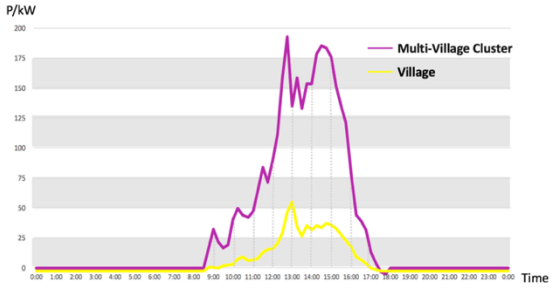
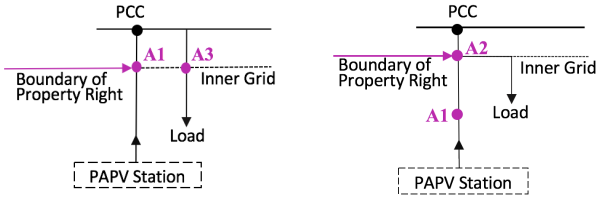


Figure 2 Generation Curves of PAPV stations

There are 545 PAPV stations (512 households and 33 villages) in 380/220V networks, and 44 in 10kV networks (36 villages and 8 clusters). PAPV stations sell electricity to DSO in the way of whole generation sales or surplus generation sales. Village and village cluster PAPV stations adopt whole generation sales, while household PAPV stations can choose one of them. For now, about 150 PAPV households adopt surplus generation sales.

Metering and Settlement of PAPV generation

When PAPV station integrates to distribution network, connecting and metering points should be set properly. Figure 3 shows schemes of metering points for PAPV station. A1 is necessary for PV generation metering and thus allowance; A2 is equipped with one-way metering, A3 is with two-way metering. For the settlement of surplus generation sales, PAPV adapts A1 and A2 metering. Note that it is not a settlement based on net energy, since the prices of purchasing and sales are different. For the settlement of whole generation sales, PAPV adapts A1 and A3 metering, stations connect to grid by special line.



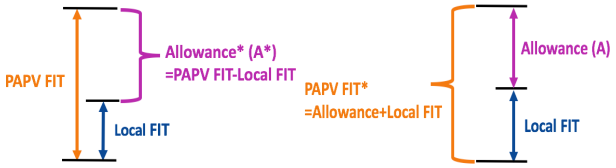
(a) Whole PV (b) Surplus PV

Figure 3 Scheme of metering points

To supporting PAPV policy, SPG-BJ provides metering equipment and installation services free of charge. SPG-BJ adopts smart meter now. PAPV station communicates with power grid dispatching centre through data transfer unit and other automatic terminal equipment. Data of PAPV station at MV network are uploaded to the SPG-BJ DSO centre every 15mins, and that at LV network are collected every 24 hours to local data collectors.

PAPV stations of surplus generation sales consume an average 10% of their generation, some up to 50% and the maximum to 95%. For all PAPV prosumers, power generation and electricity consumption are settled separately according to national policy, and DSO is responsible for both the settlements.

Pricing of PAPV generation



(a) Whole PV (b) Surplus PV

Figure 4 Scheme of PAPV Allowance

All PAPV generation is of allowance. Government sets FIT price for whole generation sales and PAPV allowance for surplus generation sales, as show in Figure 4. For whole generation sales, allowance from government is equal to PAPV FIT minus the local FIT, for surplus generation sales the PAPV allowance and the local FIT makes up an equivalent PAPV FIT. With the evolution of national renewable energy policy, PAPV FIT and PAPV allowance has changed as shown in Table 5. In 2018, the allowance of PAPV surplus generation is 0.42 RMB/kWh and the PAPV FIT price of whole generation sale is 0.85 RMB/kWh. With a local FIT price, the PAPV FIT of surplus generation is equivalent to 0.77 RMB/kWh, the allowance of PAPV whole generation equivalent to 0.50 RMB/kWh.

For the PV policy in June 2018, the FIT price of D-PV project is lowered to reduce the price distortion of renewable energy on electricity market, while PAPV allowance policy remains unchanged, keeping higher than that of general D-PV projects.

Table 5 PAPV Allowance in SPG-BJ Area (RMB)

Year	Local FIT	Whole PV		Surplus PV	
		FIT	A*	A	FIT*
2016	0.33	0.98	0.65	0.42	0.75
2017.01-06		0.85	0.52		0.75
2017.07-Now	0.35	0.85	0.50		0.77

The allowance of PV generation is paid by the Renewable Energy Development Fund and transferred to customers by SPG-BJ DSO. In 2018, the electricity sales price to resident customers in SPG-BJ supply area is 0.50 RMB/kWh. The self-consumption of PAPV surplus sales customers is exempted from all kinds of fund fee and additional levies with electricity price, as well as the system reserve capacity fee and other related grid-connected fees. In addition, VAT is exempted for s、mall-scale owners given whose monthly sales income and allowance PAPV generation do not exceed 30,000 RMB.

From the point of DSO's view, the PAPV whole generation sales mode does not reduce DSO's sales, and ensures DSO's actual benefits of and reduces DSO's electricity purchase from distant power plants, thereby reducing system network losses and achieving economic benefits. On contrary, under the mode of surplus generation sales, the self-consuming reduces electricity bills. However, it may lead to cost-recovery mismatch between DSO investment and customer cost.

In SPJ-BJ supply area, it is required that all local generation is balanced by local load and without a reverse power-flow to upper stream grid, i.e. SG's grid. There have been many small hydropower plants in SPG-BJ supply area. Because of the increasing PAPV installations, reverse power flow to SG transmission network could sometime be unavoidable and without any settlement, which reduce the investment efficiency of PV stations.

Business Model of PAPV projects

As an innovative strategy of poverty alleviation in rural areas, PAPV project should have sustainability in return. For now, initial investment is a focus of business model

and one of the key indicators to evaluate PAPV projects. Different regions and conditions may have different composition of initial investment. Table 6 shows the investment composition of all PAPV projects in SPG-BJ supply areas.

Table 6 Investment composition（*10^6 RMB）

County	Capital Base				Bank Loan	Σ
	Gov.	Enterprise		Donation		
		Funding	Advance			
FX	2.9			0.1		3.0
FF			3.0			3.0
LX	41.9		1.1	1.3		44.3
MX	7.0					7.0
QS	5.5				2.7	8.2
QY	22.0		22.3	4.8	2.9	52.0
TB	5.2			0.7		5.9
LY	22.3	1.1		0.6		24.0
Σ	106.8	1.1	26.4	7.6	5.6	147.5

Among the initial investment of PAPV projects, government investment accounts for more than 70% of the total and is the main source of investment. For counties with less poverty households, government take in charge of full investment. National poverty alleviation funds and local government subsidiary funds are the main forms of government investment. On the principle of voluntariness, enterprises can make direct donations or advance payments, and provide products and construction operation and maintenance. At the same time, residents can raise their own funds through bank loans, and pay back enterprises or loans with PAPV plant income. New policy requires that PAPV power plants connected to the grid after March 2018 must be fully invested by the government, and no enterprise investment with forms of requiring income return is allowed, so as to ensure the annual income of poverty households and the public welfare of the project.

In the SPG-BJ supply area, there are many elders living far from village centre and without income sources. Government invests village bead-house with PAPV projects and invites the elders to live there; the profits of PAPV generation are to village collectives and elderly homes. At the same time, economic cooperatives such as "PV+" agriculture were established to promote the implementation of PAPV projects.

For PAPV projects, revenue is from generation sales and allowance minus costs, as in Eq. (1).

$$R = S + A - C \quad (1)$$

Where R is the annual revenue, S the sales income, A the allowance from government, C the investment repay and cost.

For an 5kW household's PAPV station, annual generation is about 6200kWh, an annual utilization rate is over 1100 hours, the household obtains annually an allowance 3,100 RMB and the sales income 2,170 RMB. The annual income of each household's PAPV station reaches about 5,300 RMB

In 2018, PV investment cost can be low as 4000RMB/kW. Considering that the government PAPV project has a very low loan interest, the investment recovery period can be extended to 10 years, maintenance cost of small scale PV station is neglectable, the annual revenue of the PAPV household reaches the national requirement of 3,000RMB in SPG-BJ.

SPG, as a regional independent grid enterprise, makes monthly settlement of electricity generation into grid and consumption from grid. Allowance of PAPV stations are from government subsidies and is transferred by SPG-BJ. SPG-BJ usually declares the allowance to the government every three months. The procedures for provincial governments to collect subsidies through renewable energy funds are complex and prone to delay. To a certain extent, this increases the payback period of investment and reduces the income distributed to the PAPV owners. Considering the demand of initial construction investment and the O&M costs, PAPV allowance have a greater impact on private enterprises which rely heavily on cash flow, and could even lead to the breakdown of the capital chain of PV investment enterprises and brings certain economic pressure for residents to repay loans.

Distribution Network with PAPV stations

Rural areas are sparsely populated and loaded. Considering the economy of distribution network investment, it is common to have fewer power stations, lines of long distribution distances and small sections. Capacity of village MV/LV transformer in rural areas are about 30kVA~400kVA.

Distribution networks of SPG-BJ has the characteristics of wide coverage, unbalanced developments of various areas, relatively small and decentralized loads. In LV distribution network, low level of equipment and lines results in low voltage, three-phase unbalance and other problems. SPG-BJ has been upgrading and renovating the rural distribution network for PAPV projects. However, with the large-scale integration of PAPV, impacts on power quality, network loss and power fluctuation are greatly obvious. In the process of PAPV grid-connection, there have occurred of line jams, transformer capacity deficient, line section not large enough, etc.

In addition, planned or unplanned island operation of PAPV stations is not allowed in SPG-BJ power grid at present. With the increase of PAPV power stations in the future, the operation reliability of SPG-BJ grid is more demanding, and directly affect the operation reliability and benefits of PAPV projects.

DEVELOPMENT CHALLENGE

During the PAPV development, PAPA projects and DSOs face new challenges as shown in Figure 5, including funds and finance, network planning, system operation, and other technical issues.

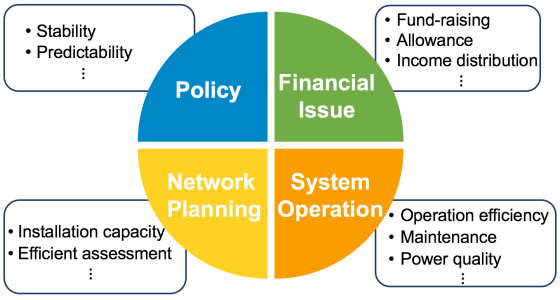


Figure 5 PA-PV Challenges for DSO

Policy and Finance

China's PV power policy has changed as a whole in 2018, but the PAPV policy unchanged. Policy stability and predictability is important for sustainable PAPV development.

Delay of PAPV allowance increase investors' worries and burdens, and may even affect the survival of some investment enterprises.

"PV+" project of village cluster type can get both the power generation income and agricultural income, and may become a favorite model. However, compared with village PV stations, village clusters face more difficulties, in fund-raising, construction land, income distribution and power grid reinforcement.

Planning and operation

In March 2018, four national standards for PAPV planning was issued, namely, "*Targeted Poverty Alleviation-Technical Guide of Village PV Power Stations*", "*Targeted Poverty Alleviation-Management and evaluation guide of PV Power Stations*", "*Guide for Planning and Design of the Rural PV Power Station Cluster Connected to Power Grid*", "*Requirement for the Control Function of the rural PV Power Station Cluster*". Construction of PAPV stations, technical requirements for the design, construction, installation, commissioning and acceptance, operation and maintenance of the power stations are specified. These national standards are formally implemented in Oct 2018, and will play an important technical supporting role in PAPV stations, to improve the construction quality, the operation and maintenance level, the effectiveness of PAPV station, and to promote economic development and livelihood improvement in poverty areas.

During the network planning, installation capacity assessment should include, selections of grid connection point and connection configuration; while scale of power station construction are closely related to grid conditions of connected points, small load and security of rural power network are fundamental attributes. Power grid benefit assessment includes assessment of primary transformer investment, loss, grid access capacity, and grid evaluation for general purpose or specific project. To give full consideration of the local absorption capacity to eliminate PV generation curtailment or the situation of reverse power flow without settlement.

With the PAPV increasing in rural distribution network, the improvement of DSO's functions, such as load forecasting, voltage control, network analysis of line and transformer overload loss, bidirectional power flow, PV station remote monitoring and controlling are necessary to ensure the power grid operation security. The operation efficiency of PAPV stations is fundamental to the generation capacity, and depends on the equipment quality, the operation and maintenance level. It is proposed that the innovative operation and maintenance by digital technology application to PV power stations. Application of digital technology can not only directly improve the operation and control level of distribution network, but also improve the power grid planning, where the biggest obstacle is the optimization of cost-benefits.

Power quality management

In principle, power quality needs to meet the requirements of the corresponding national standards. For now, power quality control for PAPV stations includes the power quality detection when connecting to the grid. During network planning, power quality assessment is rather simple; during operation, there is seldom power quality monitoring in LV/MV networks. In the future, with the increase of PV power station, power quality management and monitoring need more attention.

CONCLUSION

The implement of China's PAPV policy shows very positive results in a very short time. Under PAPV policy, distributed PV power has rapidly increased in the weakest distribution networks, and brings DSOs new roles and new business. Recent studies focus on the benefits and optimization analysis of the PAPV project investment, the planning and optimization of rural MV/LV networks. In 2016~2020，PAPV power is expected to be one important part of China's distributed PV development. With an increasing integration of PV power in rural distribution network, changes of grid configuration and operation characteristics should definitely bring new challenges to local DSOs, which need to pay more research focuses.

REFERENCES

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