Feasibility Study on County Scenario of Virtual Power Plant Participating in Rural Energy Internet

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Abstract. In order to solve the problems existing in the energy Internet, let the virtual power plant participate in the energy Internet and solve the problems existing in the energy Internet. Firstly, starting from the resources that can be aggregated in the county, the county scene of virtual power plant participating in rural energy Internet is constructed. Then, in order to study the feasibility of virtual power plant participating in the county scene of rural energy Internet, an economic evaluation model of virtual power plant participating in the county scene is constructed from the perspective of cost-benefit. Finally, a virtual power plant is taken as an example to verify the effectiveness of the model. The empirical results show that the participation of virtual power plant in rural energy Internet can pass the evaluation of technology and economy.

Keywords: Virtual Power Plant · Feasibility Study · Rural Energy Internet

1 Introduction

Virtual power plant is a mode of application of source and bilateral interaction. It is a "source of Internet plus" smart energy environment, user centered, and commercialized market as the platform of the source network convergence management mode, which combines the distributed generation units, controllable load and distributed energy storage facilities. Through the supporting regulation and control technology and communication technology, it can realize the integrated regulation and control of all kinds of distributed energy, participate in the operation of power market and power grid as a special power plant, aggregate distributed energy to participate in the operation of power market and auxiliary service market, and provide management and auxiliary services for distribution network and transmission network [1, 7, 9].

Literature [4, 5] first lists the overall framework of the intelligent operation optimization management integrated platform of virtual power plant. Then it analyzes the seven functions of the platform, such as three-phase modeling function of transmission and distribution grid, three-phase state estimation function, distributed generation prediction function, user load prediction function and three-phase power flow calculation

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function, and analyzes the application of the intelligent operation optimization management integrated platform of virtual power plant. Literature [2] introduces the background of developing virtual power plant, expounds the key technology application of virtual power plant, the construction of external operation platform and the design of internal regulation interaction mechanism, summarizes the actual implementation and highlights of virtual power generation, analyzes the results and current problems, and puts forward further ideas for the application of virtual power plant in commercial buildings in the future. Based on the connotation and types of virtual power plant and energy storage technology, literature [3] analyzes the application of energy storage technology in virtual power plant in combination with practice. Based on the analysis of the concept, characteristics, structure and function of virtual power plant, literature [8, 10] focuses on the research and discussion on the application of virtual power plant in distributed photovoltaic power generation application demonstration area, analyzes the application prospect and preconditions of virtual power plant, and finally puts forward the problems that should be paid attention to in the future development of virtual power plant.

Based on the typical application research of virtual power plant, starting from the resources that can be aggregated in the county, this paper constructs the county scene of virtual power plant participating in rural energy Internet. Then, in order to study the feasibility of virtual power plant participating in the county scene of rural energy Internet, an economic evaluation model of virtual power plant participating in the county scene is constructed from the perspective of cost-benefit. Finally, a virtual power plant is taken as an example to verify the effectiveness of the model.

2 Cost-Benefit Model of Incremental Distribution Network with Different Operation Modes

By the end of 2020, Lankao County has connected 785.6 mW of new energy to the grid. Among them, there are 7 centralized wind power projects of 447 mW, 3 decentralized wind power projects of 27 mW, 9 photovoltaic projects of 263 mW, 2 garbage and biomass power generation projects of 39 mW, 1 energy storage power station of 9.6 mW, and the total installed capacity of photovoltaic poverty alleviation projects is 35.35 mW.

Through advanced communication, calculation, dispatching and market means, a large number of decentralized wind power, photovoltaic, energy storage, electric vehicles, controllable loads and other energy resources in Lankao County are managed uniformly, so as to fully tap and release the flexibility of the system, improve energy efficiency, reduce energy costs and promote low-carbon energy.

According to the actual load of the whole society on typical days of each season in Lankao from October 1, 2020 to September 30, 2021 and the installed capacity and output of candidate resources of virtual power plant, the county scene of Lankao virtual power plant is divided into typical seasonal scenes of spring, summer, autumn and winter. The difference of each scenario mainly lies in the difference of aggregated resources, and controllable loads such as cooling load are considered in summer and controllable loads such as heating load are considered in winter. The details are as shown in Table 1.

Lankao County is the main body of a virtual power plant. When there is a demand for clean energy consumption in the county, Lankao local initiates a virtual power plant to

Table 1. Aggregated resources of county scenes in different seasons

Season	Aggregate resources
Spring	Ning'an wind power (50 mW), sanyizhai wind power (45 mW), Taifeng wind power (95 mW), Senyuan photovoltaic (200 mW), Dongbatou wind power (11 mW), Ruihua environmental protection (24 mW), Guangfeng wind power (10 mW), energy storage power station (9.6 mW), electric vehicle
Summer	Fanzhai wind power (59.4 mW), Rongchang wind power (50 mW), sanyizhai wind power (45 mW), Taifeng wind power (95 mW), xuran wind power (48 mW), Senyuan photovoltaic (200 mW), Dongbatou wind power (11 mW), Everbright environmental protection (15 mW), Ruihua environmental protection (24 mW), Guangfeng wind power (10 mW), Yuanfeng wind power (170 mW), energy storage power station (9.6 mW), electric vehicles and air conditioners, electric fans cooling load such as cold energy storage
Autumn	Fanzhai wind power (59.4 mW), Rongchang wind power (50 mW), Taifeng wind power (95 mW), Senyuan photovoltaic (200 mW), Everbright environmental protection (15 mW), energy storage power station (9.6 mW), electric vehicle
Winter	Fanzhai wind power (59.4 mW), Ning'an wind power (50 mW), sanyizhai wind power (45 mW), Taifeng wind power (95 mW), Senyuan photovoltaic (200 mW), Dongbatou wind power (11 mW), Everbright environmental protection (15 mW), Guangfeng wind power (10 mW), energy storage power station (9.6 mW), electric vehicles, electric heating, air conditioning, thermal energy storage and other thermal loads

participate in demand response or peak shaving service, and aggregates the flexible load with rapid regulation ability in the county to participate in the peak shaving auxiliary service market for peak shaving bidding. The coordination mechanism between Lankao County virtual power plant and external power grid can be divided into three types: first, the virtual power plant plays the same role as the traditional power plant, and the external power grid is responsible for unified dispatching, so as to formulate the dispatching plan of the virtual power plant. Second, after the virtual power plant completes the joint dispatching between the external power grid and the virtual power plant, the external power grid determines the output of the virtual power plant. The virtual power plant will conduct internal optimization and formulate the output plan of the internal resources of the virtual power plant according to the optimization results of the external power grid. Third, the virtual power plant shall conduct internal optimization first, formulate the internal optimization plan and then report it to the external power grid. The external power grid shall optimize according to the dispatching plan reported by the virtual power plant and formulate the operation plan of the power grid.

3 Economic Evaluation Model of Virtual Power Plant Participating in County Scene

The technical and economic analysis combines professional technology and economic analysis. Based on the technical analysis, combined with the methods of economic analysis and effectiveness evaluation, the best decision plan of the comprehensive evaluation of economic evaluation in different technical schemes is determined, and the advanced technology and economic rationality are determined.

In the process of virtual power plant participating in the application of rural energy Internet technology, due to the various objects of various technologies, it is necessary to analyze the technical parameters to evaluate the economic effect of its life cycle, and analyze the life cycle cost-benefit and project capital benefit of each typical application.

Among them, cost-benefit, from the perspective of benefit, not only needs to calculate the expenditure and income of the project itself, but also needs to fully consider the social benefits generated by the project. From the perspective of cost, we should consider not only the direct cost required for the construction and application, but also the social cost, that is, the energy consumption cost of users in the future. The so-called time value of capital means that the various values obtained at different times are different, so it is necessary to calculate the time value of capital, which can be calculated by dynamic investment payback period, internal rate of return method, net present value method, etc.

3.1 Cost Effectiveness

The cost of the virtual power plant at the end of the project's life cycle, the residual value of the project's investment in the whole year of operation, and the cost of the virtual power plant at the end of the project's life cycle.

3.1.1 Initial System Investment

The initial investment cost refers to the total price actually paid when the investment is obtained, including taxes, handling charges and other related expenses. The initial investment of the system determines the difficulty and economic benefits of virtual power plant participating in the construction of rural energy Internet project to a certain extent. The initial investment of virtual power plant participating in the construction of rural energy Internet project is the total investment cost of each equipment:

$$C_o = \sum_{i=1}^{n} (I_i \times V_i) \tag{1}$$

Where, C_o is the initial investment of the system. I_i is the unit investment of type i equipment. V_i is the capacity of type i equipment. n is the number of equipment types.

3.1.2 Annual Operation and Maintenance Cost of the System

The annual operation and maintenance cost of the system refers to the annual equipment consumption cost, repair cost, maintenance cost, etc. The annual operation and maintenance cost of virtual power plant participating in rural energy Internet project is the total operation and maintenance cost of each equipment:

$$C_y = \sum_{t=1}^{T}(\sum_{i=1}^{n}(Y_i^t \times V_i^t)) \tag{2}$$

Where, C_o is the annual operation and maintenance cost of the system. Y is the unit maintenance cost of type i equipment. t is the number of annual operation and maintenance.

3.1.3 Annual Cost of Initial System Investment

In economic analysis, annualized cost is to annualize the initial cost of system investment, and its equation is:

$$C_a = \left\{[1 - S_v \times P_{WF}(i, n)] \times C_o + \sum_{t=1}^{n} F_t \times P_{WF}(i, t)\right\} \times C_{RF}(i, n) \tag{3}$$

Where, C_a is annualized cost. C_o is the initial investment. S_v is the residual value coefficient after the economic life. $P_{WF}(i, n)$ is the discount factor. F_t is the operation and maintenance cost and tax consumed in year t. $C_{RF}(i, n)$ is the fund recovery factor. i is the discount rate, which refers to the bank interest rate. Among them, the discount coefficient and fund recovery coefficient are respectively:

$$P_{WF}(i, n) = (1 + i)^{-n} \tag{4}$$

$$C_{RF}(i, n) = i(1 + i)^n / \left[(1 + i)^n - 1\right] \tag{5}$$

3.1.4 Annual Energy Supply Income of the System

System income determines its economic level. Compared with traditional energy systems, rural energy Internet projects involving virtual power plants can reap certain economic benefits, which are expressed as follows:

$$B_{GN} = Q_{GN} \times P_{GN} \tag{6}$$

Where, B_{GN} represents the energy supply income of the system. Q_{GN} is the total energy supply. P_{GN} is the unit price of system energy supply.

3.2 Cost Effectiveness

For the life cycle assessment of the project, indicators such as internal rate of return, net present value, dynamic investment payback period and dynamic profit and loss balance analysis can be used.

3.2.1 Net Present Value

Net present value (NPV) refers to the difference between the net cash flow generated by the investment scheme discounted at the capital cost as the discount rate and the present value of the original investment. Net present value method is a method to evaluate the advantages and disadvantages of the scheme according to the size of net present value. If the net present value is greater than zero, the scheme is feasible, and the greater the net present value, the better the scheme and the better the investment benefit. The calculation equation is as follows:

$$NPV = \sum_{t=1}^{n} (CI - CO)_t/(1 + i)^t \tag{7}$$

Where, CI is the annual cash inflow. CO represents annual cash expenditure. i is the discount rate. t is the number of years.

3.2.2 Internal Rate of Return

Internal rate of return refers to the discount rate when the total present value of capital inflow is equal to the total present value of capital flow, that is, the net present value is equal to zero. The larger the index, the better. The equation is as follows:

$$\sum_{t=1}^{n} (CI - CO)_t/(1 + IRR)^t = 0 \tag{8}$$

Where, CI is the annual cash inflow. CO represents annual cash expenditure.

3.2.3 Dynamic Payback Period

Dynamic investment payback period refers to the time required to make the accumulated economic benefits equal to the initial investment cost. Investors often care about when they can recover the cost, so as to reduce the risk. It is calculated as follows:

$$\sum_{t=1}^{T} (\mathrm{CI} - \mathrm{CO})_{\mathrm{t}}/(1 + \mathrm{i_c})^{\mathrm{t}} = 0 \tag{9}$$

Where, T is the dynamic investment payback period. CI and CO are cash inflow and cash outflow in year t respectively. i_c is the benchmark rate of return, which is the minimum acceptable return level of the investment project determined by investors from a dynamic perspective. The benchmark rate of return mainly depends on the composition of capital sources, opportunity cost of investment, project risk and inflation rate.

4 Example Analysis

4.1 Basic Data

Based on the economic analysis of the typical application scenarios of Henan Lankao virtual power plant participating in rural energy Internet, the electricity price in each period is shown in Table 2, and the unit cost is shown in Table 3 [6].

Table 2. Electricity price in each period

Time interval	Price/(¥/kW·h)
peak 9:00–11:00&18:00–22:00	0.65
flat 12:00–17:00&23:00–24:00	0.40
valley 1:00–8:00	0.25

Table 3. Unit cost

Equipment	Parameter name	Value and unit
Wind turbine	Unit construction cost	8000 yuan/kW
	Operation and maintenance cost	0.0075 yuan/kWh
Photovoltaic unit	Unit construction cost	4300 yuan/kW
	Operation and maintenance cost	0.005 yuan/kWh
Biomass unit	Unit construction cost	10000 yuan/kW
	Operation and maintenance cost	0.006 yuan/kWh
Energy storage power station	Unit construction cost	200 yuan/kW
	Operation and maintenance cost	0.005 yuan/kWh

Taking the construction period as one year and the operation period as 15 years as the calculation cycle, the residual value rate of equipment is set at 5%. It is assumed that the equipment generates electricity according to the average generating capacity, and the energy supply of the unit can be sold. The output of the equipment in the first year of operation is calculated as 50% of the typical daily output. The operation and maintenance cost is calculated by using the prediction data of the typical daily output from the second year of operation. The sales revenue and tax are calculated as 17%, the income tax rate is 33%, and the discount rate is 8%, calculating the investment payback period, internal rate of return, net present value and other technical and economic indicators of the typical scenario of virtual power plant participating in rural energy internet.

4.2 Example Results

4.2.1 Cash Flow Results

The annual cash flow results of county scenarios are shown in Table 4.

It can be seen from Table 4 that in the county scenario, except that the cash inflow in the 15th year includes 5.4293 million yuan to recover the residual value of fixed assets, the cash inflow in other years is only energy sales income, of which the energy sales income in the first year is 22.8622 million yuan, and the energy sales income in other years is 35.7255 million yuan. In terms of cash outflow, the initial construction investment is 108.5851 million yuan, and the cash outflow in other years is composed of operation and maintenance cost, sales tax and surtax and income tax. Except that

Table 4. Cash flow statement (10000 yuan)

Year	Entry name					
	Cash inflow		Cash outflow			
	Energy sales revenue	Recovery of residual value of fixed assets	Construction investment	Operation and maintenance cost	Sales tax and surcharges	income tax
Year 0			10858.51			
Year 1	2286.22			87.74	388.657	597.241
Year 2	3572.55			102.19	607.334	944.799
Year 3	3572.55			102.19	607.334	944.799
Year 4	3572.55			102.19	607.334	944.799
Year 5	3572.55			102.19	607.334	944.799
Year 6	3572.55			102.19	607.334	944.799
Year 7	3572.55			102.19	607.334	944.799
Year 8	3572.55			102.19	607.334	944.799
Year 9	3572.55			102.19	607.334	944.799
Year 10	3572.55			102.19	607.334	944.799
Year 11	3572.55			102.19	607.334	944.799
Year 12	3572.55			102.19	607.334	944.799
Year 13	3572.55			102.19	607.334	944.799
Year 14	3572.55			102.19	607.334	944.799
Year 15	3572.55	542.9255		102.19	607.334	1123.964

the operation and maintenance cost, sales tax and surcharges and income tax in the first year were 877400 yuan, 3886600 yuan and 5972400 yuan respectively, and the income tax increased by 11.2396 million yuan due to the increase of cash inflow caused by the residual value of recovered fixed assets in the 15th year, the operation and maintenance cost, sales tax and surcharges and income tax in other years were 102.19 million yuan, 6.0733 million yuan and 9.448 million yuan respectively. The net cash flow statement of each year is shown in Table 5.

It can be seen from Table 3-31 that in the county scenario, the cumulative net cash flow from year 7 is positive, the cumulative net cash flow from year 9 is positive, and the cumulative net cash flow from year 15 is 50.2182 million yuan.

4.2.2 Technical and Economic Results

According to the example results, the technical and economic indicators of this scenario are calculated as shown in Table 6.

Table 5. Net cash flow statement (10000 yuan)

Year	Entry name			
	Net cash flow	Cumulative net cash flow	Net present value of net cash flow	Net present value of accumulated net cash flow
Year 0	−10858.510	−10858.510	−10858.510	−10858.510
Year 1	1212.581	−9645.929	1122.760	−9735.750
Year 2	1918.228	−7727.701	1644.571	−8091.179
Year 3	1918.228	−5809.473	1522.751	−6568.428
Year 4	1918.228	−3891.246	1409.955	−5158.473
Year 5	1918.228	−1973.018	1305.514	−3852.959
Year 6	1918.228	−54.790	1208.809	−2644.150
Year 7	1918.228	1863.438	1119.267	−1524.883
Year 8	1918.228	3781.665	1036.359	−488.524
Year 9	1918.228	5699.893	959.591	471.067
Year 10	1918.228	7618.121	888.511	1359.578
Year 11	1918.228	9536.349	822.695	2182.273
Year 12	1918.228	11454.576	761.755	2944.028
Year 13	1918.228	13372.804	705.328	3649.356
Year 14	1918.228	15291.032	653.082	4302.438
Year 15	2281.988	17573.020	719.378	5021.815

Table 6. Technical and economic indicators

Technical and economic indicators	
Static investment payback period	6.03 year
Dynamic payback period	8.51year
net present value	5021.82 ten thousand yuan
Internal rate of return	14.62%
Investment profit rate	17.67%

Through the technical and economic evaluation of the county scene, when the discount rate is 8% and the operation period is 15 years, the static investment payback period of this model is 6.03 years, the dynamic investment payback period is 8.51 years, the net present value is 50.2182 million yuan, the internal rate of return is 14.62% and the investment profit rate is 17.67%.

5 Conclusion

Firstly, this paper puts forward the county scene of virtual power plant participating in rural energy Internet, and further constructs the economic evaluation model of virtual power plant participating in County scene from the perspective of cost-benefit. The evaluation results are as follows: in the county scenario, the cumulative net cash flow from the 7th year is positive. At the same time, from the technical and economic results, the participation of virtual power plants in rural energy Internet can pass the technical and economic evaluation.

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