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A Clean Economic Dispatch of PV Energy Storage Connected to Grid Based on LHS-SR-GAMS Technology

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Abstract

PV output uncertainty, the PV scheduling problem has become urgent. The combined energy storage and PV can solve effectively the problem. We established the joint energy-saving economic scheduling model on PV- Storage generation, which mainly included the penalty model about PV positive deviation output and the penalty model about PV negative deviation output and "overflowing negative revenue" model. Considering the uncertainty of the PV output, this paper analyzed the prediction error distribution characteristics about PV output by the probability density estimate method. Based on the LHS (Latin hypercube sampling) –SR (scenes reduce) technology, PV uncertain output is converted into a finite PV output scenes under different probability conditions. Finally, we used the PV output scenarios as the input data, and we solved the proposed Model based on GAMS (General Algebraic Model System) software, which the optimization goal is the joint expectation maximum power generation benefit. Results show that relative to the energy-saving model of the individual uses energy storage planed output connected to grid, based on the technology of LHS- SR-GAMS, the combined energy storage and PV model planned output increased by 8%, and to a certain extent, improved the PV output prediction accuracy.

Keywords: *PV and storage, GAMS, positive and negative deviation, overflowing negative benefit, clean economic dispatch*

1. Introduction

As the traditional energy shortage, environment pollution is increasingly seriously, a new kind of clean energy becomes very important. The solar resources are rich in our country, and PV power generation has many characteristics, such as sustainable, no pollution[1-3].The state council issued ‘Solar power technology development "twelfth five-year" special planning’, and will make PV capacity more and more big. But PV domestic mainly used in the form of a large, centralized grid, PV short-term output prediction precision is low, output uncertainty (clouds) makes the grid PV power generation scheduling is the very difficult problems urgently needed to solve.

With the application of energy storage technology, maturity and lower cost, PV storage power generation become the effective way to solve the above problems, such as domestic has implemented Zhang Bei PV and wind storage key demonstration project. When PV actual output values greater than planned output value, the energy storage devices can store the extra power; when the actual output value is lower than the planned output value, the energy storage devices can release the power, avoided short of output power planned value and received the punishment of the power sector [4-7], and it can improve the efficiency of the photoelectric. Now the main energy storage including fly wheel energy storage, pumped storage, compressed air energy storage, battery, etc. [10].

In the literature [11] proposed wind farm the concept of "negative effect" operation, they established the model about a large-scale wind power grid interconnection optimization scheduling, but they did not consider the output prediction error, and a lack of practicality. Literature [12] put forward the grid-connected static scheduling model about PV power generation with generating cost minimum as the objective. Literature [13] considering grid the biggest accept PV power generation capacity, it put forward abandon PV punishment cost, and

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they established the static scheduling model. Literature [14] considering the PV prediction error, it put forward the dynamic scheduling model based on PV prediction error. But it didn't analysis distribution characteristics of the prediction error, which would have a great influence on scheduling results.

Most of the above documents did not consider photovoltaic output prediction error when arranging schedule, thus ignoring the photovoltaic output uncertainty. which would affect the safety of power grid, makes the power sector increased system reserve capacity, leading to the increased cost of power generation; Based on combined power generation and PV storage scheduling problem, integrated national new energy generation such as PV encouragement policy and the influence of PV power generation on power grid safe operation. Considering encourage PV power generation about combined PV storage output, we established respectively positive deviation revenue model and negative deviation punishment revenue model, and we put forward the consideration grid of PV maximum given capacity of "overflowing negative revenue" model. Then based on several kinds of revenue model put forward by the paper, we established combined PV storage power energy-saving economic dispatch model. Which considering the uncertainty of PV output combined with the actual situation of PV output in a revenue model, in order to solve the proposed model, this paper analyzed distribution characteristics of the PV output prediction error based on the probability density estimate; Based on the LHS (Latin hypercube sampling) –SR (scenes reduce) technology, PV uncertain output is converted into a finite PV output scenes under different probability conditions, which provided the basis calculating data for PV scheduling model. Finally, we chose a PV power station in Xinjiang as an example, and we solved the proposed Model based on GAMS (General Algebraic Model System) software, which the optimization goal is the joint expectation maximum power generation benefit. Results show that the proposed method is effective, and had good engineering application value.

2. PV Storage Connected-grid Energy-saving Economic Optimization Scheduling Model and Solving

According to the engineering actual situation, the model proposed by the paper needed to consider the photovoltaic power output uncertainty. So this paper firstly analyzed the distribution of PV output prediction error based on the probability density estimation methods, which combined the PV predict output value to PV forecast distribution characteristics, based on the LHS - RS technology sampling and reducing, forming a limited output. Secondly, in the process of scheduling modeling integrated state for PV power generation encouragement policies and PV power generation for the influence of the safe operation of power grid and PV output uncertainty, we established PV store joint power energy-saving economic dispatch model. Finally using GAMS software written energy-saving economic dispatch model and solving the PV output scenes number. The general idea is shown in Figure 1.

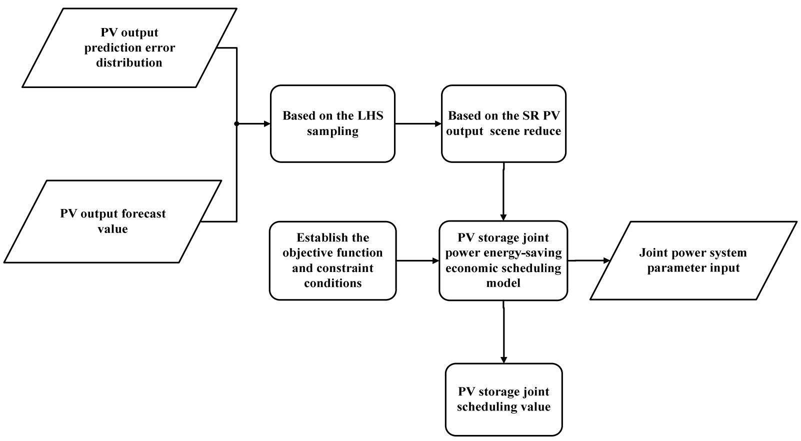

Figure 1. The Structure about the Economic Dispatch of PV Energy Storage Based on LHS-SR-GAMS

3. Determine different scenarios output of the PV

The proposed revenue model considering the uncertainty of PV output, so we needed to input the PV output scenario of all day when model in the process of calculation (see section 3). Therefore this section first introduced how to calculate PV output scenario. PV power station used prediction method is quoted in this paper is based on the improved feedback neural network about PV short-term prediction output, but too many and complicated factors influencing the PV output, resulting in the PV had a certain error. So we couldn't convert the uncertainty of the PV output into a finite number of scenarios until study the prediction error distribution, which provide basic data for the next step arrange schedule. The definition of prediction error as follows:

$$error_t(\%) = \frac{P_{real.t} - P_{fore.t}}{P_{W.\max}} \times 100\% \tag{1}$$

Which $P_{real.t}$ is the actual output of PV under the t time, $P_{fore.t}$ is the predict output of PV under the t time, $P_{P.\max}$ is the capacity of PV power station.

2.1. PV Predicted Output Error Distribution

We need to study PV output prediction distribution to find out different scenarios output. This article uses the PV output prediction error probability density function errorx (x, t) to represent the prediction error error (x, t) distribution characteristics, and solving by estimating the probability density function, the solving process is as follows:

$X_1(t), X_2(t)..X_c(t)...X_y(t)$ PV sample prediction error probability density function of $P_X(x,t)$ estimates can be obtained by density evolution. We can put the sample error as a representative process [6, 7] because it is independent, and its probability is:

$$p_c(x,t) = \frac{1}{y} \tag{2}$$

Obviously $\sum_{1}^{m} p_c(x,t) = 1$, for c ($1 \le c \le y$) representative process, the density solving evolution equation is:

$$\frac{\partial p_{X:c}(x,t)}{\partial t} + X_q(t)\frac{\partial p_c(x,t)}{\partial x} = 0 \tag{3}$$

The corresponding initial conditions as follows:

$$P_{X:c}(x,t) = \delta(x - x_{0:c})P_c \tag{4}$$

The initial value of $x_{0:c}$ is the first c sample:

$$x_{0:c} = X_c(t_0) \tag{5}$$

To solve the 3-4 type, we get $P_{X:c}(x,t)$, and we can get the probability density function estimate of $X(t)$:

$$p_{X:c}(x,t)=\sum_{c=1}^{m}p_{X:c}(x,t) \quad (6)$$

2.2. The Determination of PV Output Scenario

We through the formula 1, every prediction error corresponding to a scenario for p_i, the output for the scenario in the probability of p_i as follows:

$$P_{P.i.t}=P_{fore.t}+(e_i\times P_{fore.t}\times P_{P.\max}),i=1,..,N \quad (8)$$

Which $P_{P.i.t}$ is the ith scenario PV output under the time t, e_i is the corresponding PV output prediction error in the ith scenario, N is the sum of all the prediction error scenarios.

3. PV Output Scenario Generation and Reduction

3.1. Latin Hypercube Sampling of the Output of PV

By 1.1 we obtained the distribution characteristics of PV output prediction error, from the type 8 we could be known scene distribution of PV output. Since the Latin hypercube sampling is a improved sampling method of Monte Carlo sampling, which extracts the sample more representative of the entire sample interval, and the any size of the number of samples could easily produce [7]. So this article used the Latin hypercube sampling for effective sampling of PV output scenario, Latin hypercube sampling of PV output scenario procedure as follows:

1) It is concluded that probability distribution of the PV output scene is divided into m equal probability interval.
2) Any equal probability interval: from $m\left[(e-1)/m,e/m\right]1\leq e\leq m$ random extracted a number p_m , p_m can be expressed as:

$$p_m=\frac{r}{m}+\frac{i-1}{m} \quad (9)$$

In which r is the random variables of equal probability distribution in [0,1] .

3) We use the inverse transformation of PV forecast output distribution function, and got the probability interval $\left[(e-1)/m,e/m\right]$ of the PV output samples, namely:

$$P_{P.i.t}=F^{-1}(p_m) \quad (10)$$

3.2. PV Scenes Output Based on the Technology of Scene Reduce

By Latin hypercube sampling, with the corresponding t at a certain moment, photovoltaic output scenarios were many, forming numerous scene tree; if we did not process the scene, and the computer would face huge amount of calculation. So this paper using the scene reducing technology to reduce scene, we used the scene which had had reduced instead of multiple scenarios, thus forming a finite number of PV output collection [7]. Hypothesized the output scenario through Latin square sampling was m, reduced its scenario for n. Scene reduce at a certain moment specific steps were as follows:

a) Assuming $l=m$, l is the number of scenarios which need to reduce. Calculate any time the Kantorovich distance of $P_{P.j.t},P_{P.k.t}$ of the two *j*, *k* scenario, $j\leq l,k\leq l$.This article used the Kantorovich distance as follows:

$$d_k(P_{P.j.t},P_{P.k.t})=\left|P_{P.j.t}-P_{P.k.t}\right| \quad (11)$$

b) For every scene j, we were found the output scenario $P_{P.k.t}$ which is the shortest distance from the output scenario $P_{P.j.t}$, and namely $\min\left\{d_k(P_{p.j.t}, P_{P.k.t}), j \neq k\right\}$, set:

$$\mu_{\min j} = \min\left\{d_k(P_{p.j.t}, P_{P.k.t}), j \neq k\right\} \tag{12}$$

c) Calculate $P_{KD_{i.t}} = \mu_{\min j.t} \times p_{j.t}$, where $p_{j.t}$ is the probability of $P_{P.j.t}$.

d) Repeat steps c, in that all the P_{KD_i}, looking for the smallest $P_{KD.i.t}$. Marked for $P_{KDS.t}$ .The new scene probability for $p_{k.t} = p_{j.t} + p_{k.t}$, which the output scenarios P_{sj} need to concentrate reduce.

e) After a scene was reduced, again in a step, when the output scenario reduced to n .We can be concluded that the reduce output scenario at t time which has the number of n.

4. Based on the LHS - SR - GAMS PV Storage Connected-grid Energy-saving Economic Optimization Scheduling Model

4.1. Establish the Objective Function

Due to uncertainty of PV output, the output may be have many scenes, therefore we cannot use the objective function of a single confirmed to optimize the PV store hybrid power generation efficiency. This paper uses the expected objective function which contains random variables to describe the problem more reasonable and practical. Combined with the national related policy in new energy power generation to encourage the generation of electricity, this paper considers earnings of sell electricity, benefits of PV storage joint output deviation positive and negative deviation punishment, finally we also considered the ‘overflow negative earnings’ of the power grid to PV maximum given abilities.

$$MaxE(i, P_{PB.t}) = R_1 + R_2 - R_3 - R_4 \tag{14}$$

$$R_1 = \sum_{1}^{12} MP_t P_{PB.t} \tag{15}$$

$$R_2 = \sum_{1}^{12}\left[MP_t^{up}\sum_i (1-b_{i.t})(P_{i.jo.t} - P_{PB.t})p_{i.t}\right] \tag{16}$$

$$R_3 = \sum_{1}^{12}\left[MP_t^{down}.\sum_i b_{i.t}(P_{PB.t} - P_{i.jo.t})p_{i.t}\right] \tag{17}$$

$$R_4 = P_{dro}.\Delta P_{i.dro.t} \tag{18}$$

This article selects the PV storage joint power time is 8:00-17:59, a total of 10 hours. MP_t is the sell electricity prices at t moment, $P_{PB.t}$ is the PV storage joint plan output; MP_t^{up} positive deviation sell electricity prices, which represents the benefits of PV storage output deviation; MP_t^{down} is negative deviation punish price, which represents the benefit of PV output negative deviation penalty. The state of PV output positive and negative deviation is $b_{i.t}$; when $b_{i.t} = 1$, which represents the state of negative deviation. The PV storage overflow price is P_{dro}, which represents PV store overflow benefits. The ith scene PV store joint power output at t moment is $P_{i.jo.t}$. The ith scene PV store output overflow number at t moment is $\Delta P_{i.dro.t}$.

4.2. Establish the Constraint Condition

Firstly, we needed to the power balance constraint between PV and storage when PV and storage power generation scheduling. We also need to consider the restrictions of the PV maximum given, which contains the energy storage device charge-discharge capacity constraints, PV output constraints, energy storage device charge-discharge stored energy balance constraints in a cycle. And we needed to consider the combined power generation report capacity constraints caused by its capacity.

The output balance constraint of PV storage joint power generation:

$$P_{i.jo.t} = P_{P.i.t} + P_{dis.t} - P_{ch.t} \tag{19}$$

The restrictions of the grid biggest consumption:

$$\Delta P_{i.dro} = P_{PB.t} - P_{\mathrm{con.t}} \tag{20}$$

1) The constraints of the report output capacity:

$$0 \le P_{PB.t} \le P_{P.\max} + P_{dis.\max} \tag{21}$$

2) The power capacity constraints of energy storage devices between the moment:

$$E_t = E_{t-1} + P_{ch.t}\eta_{ch} - P_{dis.t} / \eta_{dis} \tag{22}$$

3) The power capacity constraints of energy storage devices:

$$E_{\min} \le E_t \le E_{\max} \tag{23}$$

4) Power restrictions of Energy storage charge and discharge:

$$0 \le P_{dis.t} \le P_{dis.\max} \tag{24}$$

$$0 \le P_{ch.t} \le P_{ch.\max} \tag{25}$$

5) Power balance constraints in a cycle:

$$E_0 = E_T \tag{30}$$

In which $P_{dis.\max}$ is the maximum charge power of the energy storage device; and $P_{ch.\max}$ is the minimum discharge power of the energy storage device.

5. Numerical Examples Validate

This article used a PV power station of the Xinjiang region, which PV power generation capacity is 50mw. PV power station based on feedback neural network prediction system, and its forecast interval time is 10 minutes. PV power plant put into operation for 4 years, and it has the rich local meteorological data.

5.1.1. Analysis Prediction Error Distribution Characteristics

We collected actual data and predicted data for 3 years of a certain PV power station in Xinjiang, its forecast time was 10 minutes, a total samples were 3 *365 * 10 *6, then we written the program about the probability density estimation method based on matlab, by which we can solve the prediction error. The probability distribution solved as shown.

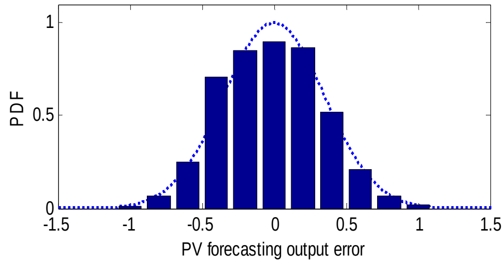

Figure 2. PV Prediction Error Distribution Diagram

From the figure we could know paragraphs prediction error distribution approximate symmetrical, and the outside line had normally distributed characteristics. Thus we concluded that the prediction error had normally distributed characteristics. Through calculation, the prediction error of a certain PV power station in Xinjiang of this paper adopted was.

$$error(t) \sim (0, 0.14)$$

5.1.2. PV Scene Output Sampling and Reduce

We concluded the distribution of PV output prediction error from the front section, then we sampled to prediction error scene based on LHS technology. The sampling number of PV prediction error scene is 2000, and combining with the PV forecast value of the PV forecast system, according to the type eight, we could get PV output scenes. Repeated the above operation, we could get PV output scenario of 10 hours.

In order to make the calculation efficiency, we written the program of PV output scene reduce based on matlab. Unlimited scene reduce would lead to the fitting degree is not high, and we cannot blindly pursue the fit of the output error, this will make the calculation efficiency is not high. The ratio of the area prediction error distribution curve and abscissa when reducing before and after was fitting. So we first chose the reduce number, which is: 15, 25, 35, 45, 55, 65.Fitting in the following Table 1.

Table 1. Storage Capacity Configuration under Different Number about Reduced PV Output Scenes

Scenes number	15	25	35	45	65
Fitting	0.68	0.74	0.85	0.87	0.9

Table 2. PV Output Scenes at 14:00 on July 25 2013

scenes	PV output（MW）	probability
1	3.3	0.0003
2	6.5	0.0027
3	14.5	0.0365
4	22.7	0.0523
5	26.1	0.1264
6	27.8	0.1153
7	31.5	0.1032
8	35.3	0.1026
9	37.6	0.1186
10	40.7	0.0733
11	42.8	0.1212
12	45.3	0.0727
13	47.8	0.0726
14	49.3	0.0021
15	50	0.0002

From the above table we could know when the number of reduce scenes was 65, the fitting was the highest, but it would affect the computational efficiency. When the number of reduce scenes was 15, and the fit ting was 0.68. If the number of reduce scenes was 15, it would greatly improve the computational efficiency. So this paper selected 15 as the number of reduce scenes. We selected forecast number of 35.3 MW of a PV power station in Xinjiang in14:00, July 25, 2013, which produced the number of 2000 output scenes by LHS, then we used the SR technology to reduce output scene. The number of 15 produced scenarios output shown in the following table.

5.2. The Implementation Based on GAMS Combined PV and Store Energy-saving and Economy Dispatching

In order to implement the method of combined PV and store energy-saving and economy system proposed by this paper, we established the model and written program base on GAMS. We chose DICOPT algorithm as the last algorithm. The whole system running time was 30 seconds. At 12:00-15:59, MP_t was 0.8 yuan/kW h, at 9:00-11:59 and 16:00-17:59 electricity price was 0.55 yuan/kW. H. MP_t^{up} and MP_t^{down} were 0.2 times of MP_t. The price of P_{dro} was 0.05 yuan/kW. J h, PV storage related parameters as shown in Table 3.

Table 3. Relevant Parameters about PV and Storage

Parameter name	Parameter value
PV capacity	50MW
Capacity of energy storage device	35MW.h
$P_{P.\max}$	50MW
$P_{dis.\max}$	30MW
$P_{ch.\max}$	29MW
η_{ch}	0.7
η_{dis}	0.69
$E_{\min}$	0
$E_{\max}$	50MW.h

We input the above data, and collected the PV forecast data, and we could enter the dispatching program. This paper chose a PV power station in Xinjiang on July 26, 2013 as the scheduled time. PV output predictive value as shown in Figure 3. Combined PV and storage output dispatch values as shown in Figure 4.

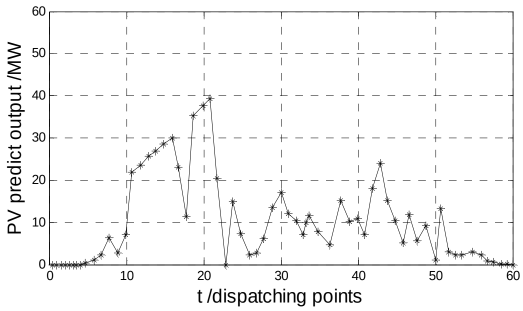

Figure 3. PV Output Forecasting Value Diagram

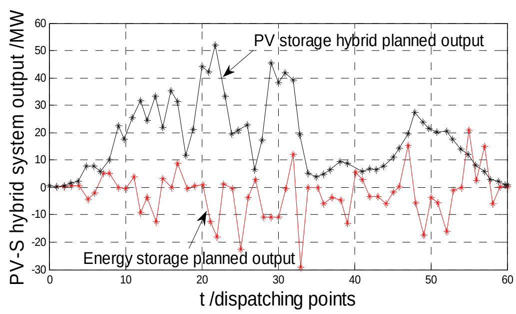

Figure 4. PV and Storage Planned Output Diagram

6. Conclusion

1) This paper concluded that PV output prediction error had characteristic of normal distribution.

This provided the basis for further research PV effect on power grid and related studies. The PV output uncertainty problem is converted into effective PV output scene with LHS - RS technology. This provided an effective solution to solve the problem of multi-scenario uncertainty.

2) Relative to the energy-saving model of the individual uses energy storage planed output connected to grid, based on the technology of LHS-SR-GAMS, the combined energy storage and PV model planned output increased by 8%, and to a certain extent, improved the PV output prediction accuracy.

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