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Storage Capacity Configuration to Improve Prediction Accuracy of Photovoltaic Output

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Abstract

The short-term prediction accuracy of Photovoltaic(PV) output may not meet power scheduling requirements, the combined use of photovoltaic generator and energy storage device can improve the prediction accuracy. Storage capacity configuration is an important issue for the economy of PV plant and PV prediction accuracy. In this paper, the distribution character of PV prediction error is analyzed based on the probability density function evolution method. A storage capacity configuration model is built to consider economic prediction accuracy and capacity. A storage device controlling strategy was bulit. Last, a tracking-economic factor is defined which can be used for economic evaluation of the energy storage device. An example is shown that PV prediction error is in normal distribution and the proposed method can improve the prediction accuracy of PV output while increasing the level of economic use of energy storage devices.

Keywords: *PV short-term output, prediction error, storage configuration, economic evaluation*

1. Introduction

Due to the conventional energy supply crisis and the emergence of increasingly serious environmental pollution, solar photovoltaic attracts more attention in the world [1-3]. With PV technology getting matured and improved, the capacity of PV installed in the grid is growing, some centralized, large-scale grid connected PV power plants have been built. However, the prediction technology of PV output is not accurate enough, which increases the difficulty of power dispatching. PV output forecasting is related to weather parameters such as, light, temperature, but the current accuracy level of weather forecasting limites the prediction accuracy of PV output [4].

With the development of energy storage technology, storage is being applied in clean energy generation [5], but mostly in purpose of load shifting and suppressing power fluctuations of wind and PV generation, which is relatively matured. It is rare to use energy storage to improve PV forecasting accuracy. Literature [6] shows that PV-storage device can rise the prediction accuracy of short-term output. Literature [7] analyzes wind power prediction error with probability statistics method. Literature [8] assesses the effects of several energy storage capacities to shift load. but the assessment is not quantitative. Literature [9] studies the added storage brings in additional costs in new energy generation.

2. Storage Capacity Configuration and Its Controlling Strategy to Improve Prediction Accuracy of PV Output

A PV plant may have a generation plan based on the predicted value, but PV power is intermittent, incidental events, such as cloud cover increases the difficulty of power scheduling. The combined output of PV and storage make the PV power adjustable and controllable, as shown in Figure 1. If the actual output of PV P_{act} exceeds forecasting value P_{fore}, the energy

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storage device is charged, on the contrary, the energy storage device is discharged which the combined output may be kept as the planned value.

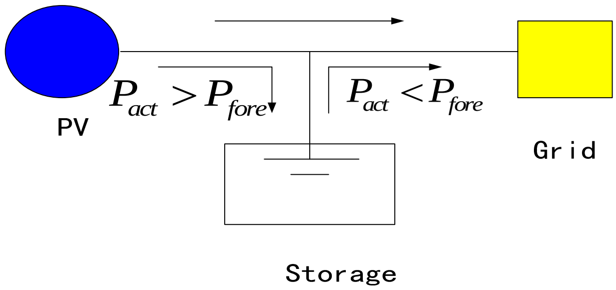

Figure 1. The PV-Store Joint System Structure Diagram

2.1. PV Output Prediction Error Analysis Based on Probability and Statistics

PV output is related to the sunlight, temperature, season and other complex factors, which result in prediction error between the real output and the prediction value, the PV output prediction error is defined in (1):

$$P_{Err} = \Delta PV = P_{fore} - P_{act} \quad (1)$$

Probability density function (PDF) of prediction error of PV output $P_X(x,t)$ describes the probability distribution of prediction error $X(t)$, which is very important information. The prediction error distribution can be obtained through probability density function estimation evolutionary. With PV prediction error samples $X_1(t), X_2(t)..X_c(t)...X_m(t)$, the probability density function $P_X(x,t)$ can be obtained.Because the samples are independent, the probability is expressed as:

$$p_c(x,t) = \frac{1}{m} \quad (2)$$

Obvious, $\sum_1^m p_c(x,t) = 1$, for c ($1 \le c \le m$),

The density evolution equation is:

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

With initial condition:

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

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

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

Based on the Equation (3) and (4), the Probability density function estimation of $X(t)$ can be obtained as:

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

With a large number of photovoltaic historical data and forecasting data, the probability distribution of prediction error can be analyzed based on the proposed method:

$$f\left(P_{Err}\right)=\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{(P_{Err})^2}{2\sigma_{Err}^2}\right) \tag{7}$$

Where $P_{Err} \sim N(0,\sigma_{Err})$, its Expectation is 0, σ_{Err} is Standard deviation.

2.2. Storage Capacity Configuration Model to Improve Prediction Accuracy of PV Output

If the discharged or charged power of energy storage P_{ES} compensate completely prediction error $P_{ES}=P_{Err}$,so, $P_{ES} \sim N(0,\sigma_{Err})$.

Assume that overall sample X is expressed as $X \sim N\left(0,\sigma^2\right)$,its expectation μ is 0, σ_{Err} is standard deviation, and $X_1,X_2,....X_n$ is from X. The confidence level $1-\alpha$ is unknown. $\overline{X}$ is an unbiased estimate of expectation μ and corresponds to expression $\frac{\overline{X}}{\sigma/\sqrt{n}}$ ~（0,1）， $p\left(\left|\frac{\overline{X}}{\sigma/\sqrt{n}}\right|< z_{\alpha/2}\right)=1-\alpha$ that is:

$$p\left(-\frac{\sigma}{\sqrt{\pi}}z_{\alpha/2}<\overline{X}<\frac{\sigma}{\sqrt{\pi}}z_{\alpha/2}\right)=1-\alpha \tag{8}$$

P_{ES} confidence interval is expressed as:

$$\left(-\frac{\sigma}{\sqrt{\pi}}z_{\alpha/2},\frac{\sigma}{\sqrt{\pi}}z_{\alpha/2}\right) \tag{9}$$

Where n is the sample number, σ_{Err} is mean variance of the forecasting output error, then $\sigma_{ES}=\sigma_{Err}$, in this paper, we choose the maximum storage output is chosen as $P_{ES}=\frac{\sigma_P}{\sqrt{\pi}}z_{\alpha/2}$, $z_{\alpha/2}=\varphi^{-1}(1-\frac{\alpha}{2})$,energy storage system capacity:

$$E_{ES}=P_{ES}\times H \tag{10}$$

Where φ^{-1} is inverse function of cumulative function of the standard normal distribution, H is consecutive hours of the positive or negative prediction error, when the grid has no sufficient spinning reserve capacity, which should be increased. From Equation (10), it can be seen that the higher the confidence level, the higher the storage capacity, the higher capacity of energy storage devices can improve short-term output forecasting accuracy.

2.3. Energy Storage Device Controlling Strategies Considering Forecasting Accuracy and Economy Evaluation

2.3.1. Energy Storage Device Discharge Controlling Strategy Considering Economy

The main structure of the storage controlling strategy is shown in Figure 2. First, PV forecasting system forecasts the PV output P_{fore} one day in advance, which are an input to the controller, the actual output P_{act} is also an input to the controller, while the controller needs to accept the charging state of the energy storage device soc. Based on the three signals, the controller generates charging and discharging signal con and the charging and discharging power, that controller is explained in the following paragraph.

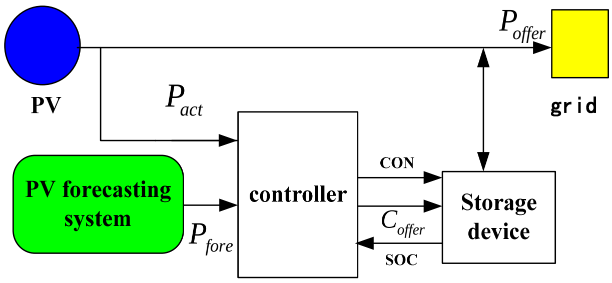

Figure 2. Energy Storage System Control Strategy Diagram

Literatures [10] have shown that considering the storage device charging state, the PV-storage generation system may offer more or less power than the forecasted, in this paper, a charging and discharging power controller is developed with taking soc into consideration.

Charging, the combined output P_{offer} of PV-storage system under the different soc is shown as Equation (11):

$$\begin{cases} P_{offer}(t_i) = P_{fore}(t_i)(1-\beta), soc \le 20\% \\ P_{offer}(t_i) = P_{fore}(t_i)(1-\gamma), 20\% < soc \le 50\% \\ P_{offer}(t_i) = P_{fore}(t_i)(1+\beta), 50\% < soc \le 80\% \\ P_{offer}(t_i) = P_{fore}(t_i)(1+\gamma), 80\% < soc \le 100\% \end{cases} \quad (11)$$

Discharging, the combined output P_{offer} of PV-storage system under the different soc is shown as Equation (12):

$$\begin{cases} P_{offer}(t_i) = P_{fore}(t_i)(1+\gamma), soc \le 20\% \\ P_{offer}(t_i) = P_{fore}(t_i)(1+\beta), 20\% < soc \le 50\% \\ P_{offer}(t_i) = P_{fore}(t_i)(1-\beta), 50\% < soc \le 80\% \\ P_{offer}(t_i) = P_{fore}(t_i)(1-\gamma), 80\% < soc \le 100\% \end{cases} \quad (12)$$

α、β is Limiting factor about the discharging or charging of the storage device

2.3.2. Economic Evaluation of Energy Storage Device

Considering the soc of the energy storage device, the combined output of PV and storage may not trace exactly the predicted output value, this paper proposes a tracking economic factor γ, which not only assesses the economy of energy storage devices, but also evaluates indirectly the effects of tracking predictive output value. γ is defined as follow:

$$\gamma = \frac{\sum |E_{com}|}{\sum |E_{theo}|} \quad (13)$$

Where $\sum |E_{com}|$ is the total compensated reserve energy by the storage to track the predicted value. $\sum |E_{theo}|$ is a total theoretical which the storage have to supply or store. When γ is 1, the energy storage device is fully tracked.

3. Results and Discussion

In this paper, a PV plant in Xinjiang, China has been chosen as an example, Based on a large number of historical data about that PV plant, the proposed method has been tested. The operating time is 13 hours (8:00-21:00) and the PVcapacity is 50MW.

3.1. Predicted Distribution Characteristics of PV Output

Due to the limitation of the weather forecasting technology as well as the complexity of factors affecting the PV output, the short-term generation forecasting system is based on artificial neural network. The PV prediction output errors are showed in Figure 3.

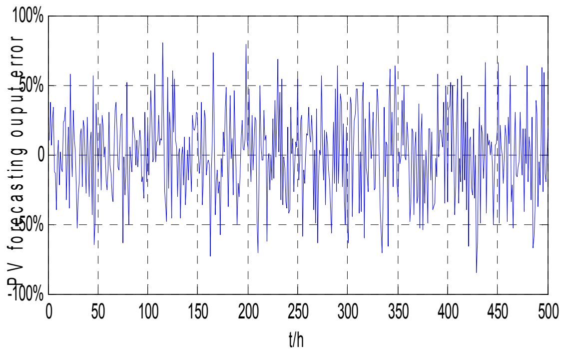

Figure 3. PV Prediction Error Distribution Diagram

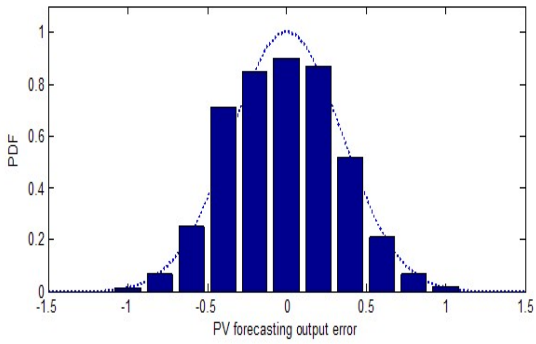

Figure 4. PV Forecasting Error Distribution Diagram

Prediction errors is divided into 9 regions, the probability of each region is gained by the proposed probability density function estimation and shown in Figure 4. It can be seen that the envelope curve of the bar graph is analogous to a normal probability density distribution, By the calculating result in this paper, the probability distribution of the prediction error of that mentioned PV is: $P_{Err} \sim (0, 0.53)$

3.2. Energy Storage Capacity Configuration

3.1 shows the PV forecasting output is expressed as $P_{Err} \sim (0, 0.53)$, according to Equation (10), we configure different storage capacities under five different confidence levels, shown in Table 1, H equals 5h,the storage capacity units is MW.h.

Table1. Storage Capacity Configuration Under Different Confidence Level

$1-\alpha$	0.80	0.85	0.90	0.95	1
E_{ES}	12.7	14.3	21.4	22.5	31.2

3.3. PV Energy Storage to Improve Prediction Accuracy and Economic Evaluation

Using MATLAB, γ values corresponding to the above-mentioned storage capacities in five different confidence levels can be obtained as shown in Figure 6, which can assess the economic effect of improving the output accuracy.

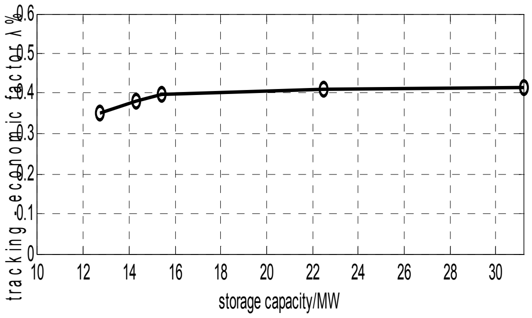

Figure 5. Tracking-economic Factor Under Different Capacity

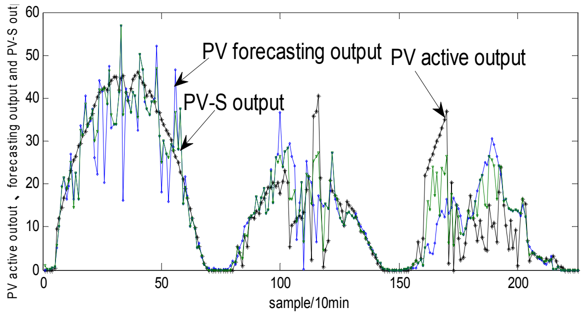

Figure 6. PV Forecasting Output, Active Output and PV-storage

Trace-economic factor λ increases linearly from12.7 to 21.4WM.h, with the increasing of storage capacity, tracking-economic factor increases slowly, but increasing the storage capacity will rise the system cost, and the improvement effect is not so significant, as shown in Figure 6. therefore the storage capacity of 22MW.h in 0.90 confidence level is chosen. It is shown in Figure 7 that the overall combined output can track predictive value and the predictive error is small from 100 to120 sampling points, but the prediction error is larger from150-180, the reason why is that the initial output error from150 to 180 is larger .the revised error by storage is shown in Figure 8

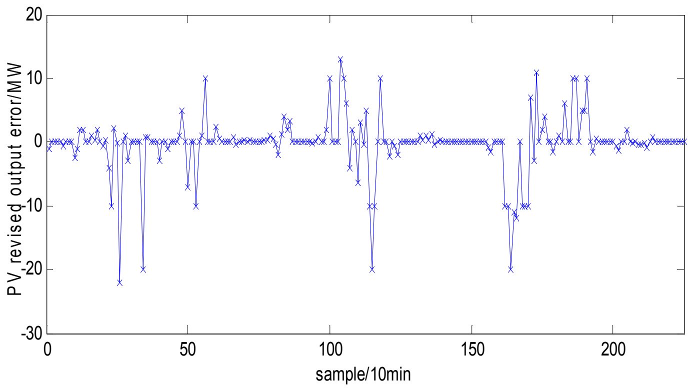

Figure 7. The Revised Predition Output Error of PV Diagram

4. Conclusion

In this paper, a new method, which employ the combined use of photovoltaic generator and energy storage device to improve the prediction error accuracy of PV output, was proposed. Firstly, the PV output prediction error is analyzed by applying the probability density function evolution method and the prediction error is obtained for the PV output with a normal distribution with zero expectation, which is $P_{ES} \sim N(0, \sigma_{Err})$. Then, With the distribution characteristic parameters of the prediction error accuracy of PV output, the configuration model of the storage capacity is built, which is $E_{ES} = P_{ES} \times H$. The storage device controlling strategy was bulit, a tracking-economic factor γ is defined, which can be used for economic evaluation of the energy storage device. Finally, a PV-connect system in xinjiang provice was chosed as a example. it is shown that the higher the confidence level, the larger the configured storage capacity. The proposed controlling strategy is effective and reasonable. A tracking-economic factor γ can evaluate the different effects about different storage capacities. the proposed method can improve the prediction accuracy of PV output while increasing the level of economic use of energy storage devices.

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