

Maximum Power Point Tracking Technology for Offshore Floating PV Based on Model Predictive Control

Tianhang Xu

*Tianjin University of Technology, Tianjin, China
tianhang@stud.tjut.edu.cn*

Abstract: A Perturb and Observation (P&O) algorithm is proposed to track the maximum power point of offshore photovoltaic power generation by disturbing the output voltage (or current) of the photovoltaic cell in this paper, and then observing the change of the output power of the photovoltaic cell, and continuously changing the direction of the disturbed voltage (or current) according to the trend of power change, so that the photovoltaic cell finally works at the maximum power point. Combined with wave fluctuation characteristics and model predictive control (mpc), the photovoltaic power generation output is predicted in the future time period, and the output of thermal power units is adjusted accordingly. The realization of maximum power point tracking and photovoltaic power generation prediction can adapt to the traditional thermal power units can not quickly track power, and solve the problem of large-scale light abandonment and offshore consumption to a certain extent.

Keywords: Offshore photovoltaic power generation, maximum power point tracking, model predictive control.

1. Introduction

Energy reform to achieve environmental protection has become an urgent issue, due to the serious consequences of greenhouse effect. As the world's largest developing country, China has set 2030 and 2060 as deadlines to achieve the goals of "carbon peak" and "carbon neutrality" respectively [1]. Exploring alternative energy sources to achieve these two goals is quite crucial, among which solar energy is one of the inexhaustible clean energy sources in the world. The abundant solar energy resources on the ocean surface is focused on offshore photovoltaic power generation, based on the vast area of the ocean and the low utilization rate of solar energy [2]. Offshore photovoltaic is mainly composed of photovoltaic panels, steel truss support platform and pile foundation assembly and connection. The design selects to complete the assembly of the support and the installation of the photovoltaic panel at the dock, and then the whole hoisting to the sea and landing on the pile foundation, the use of photovoltaic modules on photovoltaic panels to convert solar energy into electricity. Offshore photovoltaic power generation has gradually become one of the main forces of new energy power generation as a clean way of power generation.

However, facing the problem that photovoltaic offshore is difficult to absorb due to uncontrollable natural factors as a new energy generation is quite necessary. Ocean wave fluctuations, weather factors and other constraints, offshore photovoltaic output is difficult to predict, it is hard to know its maximum output; The traditional thermal power generation ramping ability is limited, can not achieve rapid power adjustment; Offshore PV to be difficult to absorb will be caused, according to the lack

of adjustable capacity (rotating reserve capacity) in the power system. Economic and security both aspects of the problem will be caused: offshore photovoltaic is difficult to absorb the need to face a certain scale of abandoned light, do not consider a large number of offshore photovoltaic power plant construction and investment costs, this part of the abandoned light cost has caused a certain economic impact; When the power generation capacity reaches a certain scale, it will have a certain impact on the stability of the power system, due to the instability and intermittently of photovoltaic power generation, which is easy to cause voltage fluctuations and frequency changes. This also leads to the power generation is still the core of the traditional thermal power unit.

The maximum power tracking technology and several typical implementation methods of maximum power tracking, including Perturb and observation methods used in this paper are systematically introduced in [3-5]. The prediction model of photovoltaic power generation is derived in [6], based on weather change; Global climate models is used to assess global changes in the frequency of warm and cloudy conditions that lead to very low PV generation in [7], both of which incorporate weather factors to study PV generation, but both use the resulting forecast data inadequately or only predict the results. Temperature and irradiance have a greater impact on photovoltaic power generation among the natural factors, the photovoltaic output in terms of temperature and irradiance respectively is studied in [8-10] and [11-12], but neither considered the two factors with irradiance as input and temperature as change condition. A photovoltaic power generation prediction model based on LSTM neural network is proposed in [13], and combined with irradiance to classify each hour of a season, improving the accuracy of prediction is focused more in this research.

A tracking model of the maximum power point of offshore photovoltaic panel output based on MPC and wave waveform changes is provided in this paper, which can predict the photovoltaic power generation situation in the future period and adjust the thermal power output in time to solve the above contradictions. Among them, MPC technology is used to predict the proposed input reference through the wave wave fluctuation law, and the state is predicted to the MPC control terminal through the state estimation feedback based on the irradiance change law and wave waveform change characteristics, so as to adjust and correct the MPPT in real time, realize the parameter advance adjustment, and achieve the maximum power fast tracking.

The main contributions of this paper are as follows:

1. A Simulink simulation model and adopts P&O algorithm is built in this project to carry out maximum power point tracking technology, achieving good tracking effect.
2. The feedback control of MPC is used to predict the irradiance changes in the next time period combined with the wave waveform changes, and the voltage and current values corresponding to irradiance are input in advance through the data to achieve advance adjustment.
3. Several groups of photovoltaic power generation prediction data under different irradiance and temperature conditions are obtained through the Simulink simulation model, and the data can be used for future prediction analysis.

The structure of this paper is as follows: in Section II, the constraint conditions of traditional thermal generating units are briefly reviewed; in Section III, the implementation of Perturb and Observation algorithm is discussed based on the Simulink simulation model, and the maximum power point tracking effect is given; in Section IV, some of the forecast data are given, and the differences and influencing factors among the data are compared and discussed; in Section V, summarizing the conclusion and the shortcomings of this paper.

2. Constraints of traditional thermal power generation

Given N : number of units, $i \in N$;

N_L : number of load nodes;

P_i : output of thermal power unit i ;

P_d^t : load demand of node d during time period t ;

P_i^t : output of unit i in time period;

P_i^{min} : minimum output of thermal power unit i ;

P_i^{max} : maximum output of thermal power unit i ;

P_l^{min}, P_l^{max} : power flow constraint of line l (bidirectional);

u_i^t : start-stop status of group i in time period t ;

a_i, b_i, c_i : coal consumption coefficient of unit i ;

$C_i(P_i)$: coal consumption cost of unit i producing at level P_i , $i \in \Omega_i$;

$C_{i,U}^t$: start-stop cost of unit i during time period t ;

$C_{i,D}^t$: shutdown cost of unit i during time period t ;

R_1, R_2 : downslope/upslope rate of the unit;

T_1, T_2 : minimum shutdown/startup time;

H_i, J_i : single start-up/shutdown cost of unit i ;

TC : total coal cost;

ρ : coefficient of thermal reserve.

2.1. Economic scheduling model of thermal power units

Thermal power units convert energy based on fossil fuels into electricity, and the production cost of thermal power unit i can be expressed as the following formula:

$$C_i(P_i) = a_i(P_i)^2 + b_iP_i + c_i \quad (1)$$

So the total fuel cost can be expressed as:

$$TC = \sum_{i \in N} C_i(P_i) \quad (2)$$

The operating constraints of thermal power units can be expressed as follows:

$$P_i^{min} \leq P_i \leq P_i^{max} \quad (3)$$

In summary, the complete economic scheduling model of thermal power units is as follows:

$$\min TC = \min \sum_{i \in N} C_i(P_i) \quad (4)$$

$$C_i(P_i) = a_i(P_i)^2 + b_iP_i + c_i, i \in N \quad (5)$$

$$P_i^{min} \leq P_i \leq P_i^{max}, i \in N \quad (6)$$

The objective function is a quadratic function and the constraints are linear constraints in the above models.

2.2. Constraint condition

The power supply side needs to be coordinated with the load side to achieve balance based on the characteristics of power generation and ready-to-use, The power balance constraints of the system can be expressed as follows:

$$\sum_{i=1}^N P_i^t = \sum_{d=1}^{N_L} P_d^t \quad (7)$$

The hot reserve constraint can be expressed as follows:

$$\sum_{i=1}^N (u_i^t P_i^{max} - P_i^t) \geq \rho \sum_{i=1}^{N_L} P_d^t \quad (8)$$

Unit output constraints can be expressed as follows:

$$u_i^t P_i^{min} \leq P_i \leq u_i^t P_i^{max} \quad (9)$$

Its actual output power can not reach the target value quickly, although the output of the thermal power unit is adjusted quickly. The corresponding unit ramping constraint can be expressed as follows:

$$-R_1 \leq P_i^t - P_i^{t-1} \leq R_2 \quad (10)$$

In the power system, it is stipulated that each unit cannot start or stop frequently within a certain period of time in order to ensure the stable operation and economy of the system, so there are certain constraints on the unit start-stop time, which can be expressed as follows:

$$\sum_{k=t}^{t+T_1-1} (1 - u_i^k) \geq T_1 (u_i^{t-1} - u_i^t) \quad (11)$$

$$\sum_{k=t}^{t+T_2-1} u_i^k \geq T_2 (u_i^t - u_i^{t-1}) \quad (12)$$

Start-stop cost constraint can be expressed as follows:

$$C_{i,U}^t \geq H_i (u_i^t - u_i^{t-1}) \quad (13)$$

$$C_{i,U}^t \geq 0 \quad (14)$$

$$C_{i,D}^t \geq J_i (u_i^{t-1} - u_i^t) \quad (15)$$

$$C_{i,D}^t \geq 0 \quad (16)$$

The power flow safety constraint (using DC power flow) can be expressed as follows:

$$P_l^{min} \leq P_l^t \leq P_l^{max} \quad (17)$$

3. Implementation model

In this section, the multi-dimensional wave fluctuation mathematical model based on the characteristics of wave waveform is presented to provide support for MPC control and real-time parameter adjustment. Then, the Simulink simulation model built by the maximum power point tracking of offshore photovoltaic power generation and the simulation operation results are presented, and the debugging data is given.

3.1. Wave wave model

Photovoltaic panels are not placed on a flat plane to receive solar radiation for power generation, but with the fluctuation of the waves, its maximum power point will also change. Combined with time, wind speed and other factors, three-dimensional modeling of wave waveform is carried out to restore the real fluctuation state of the ocean to the greatest extent, so as to better track the maximum power generation of photovoltaic panels. The wave model is shown as follows:

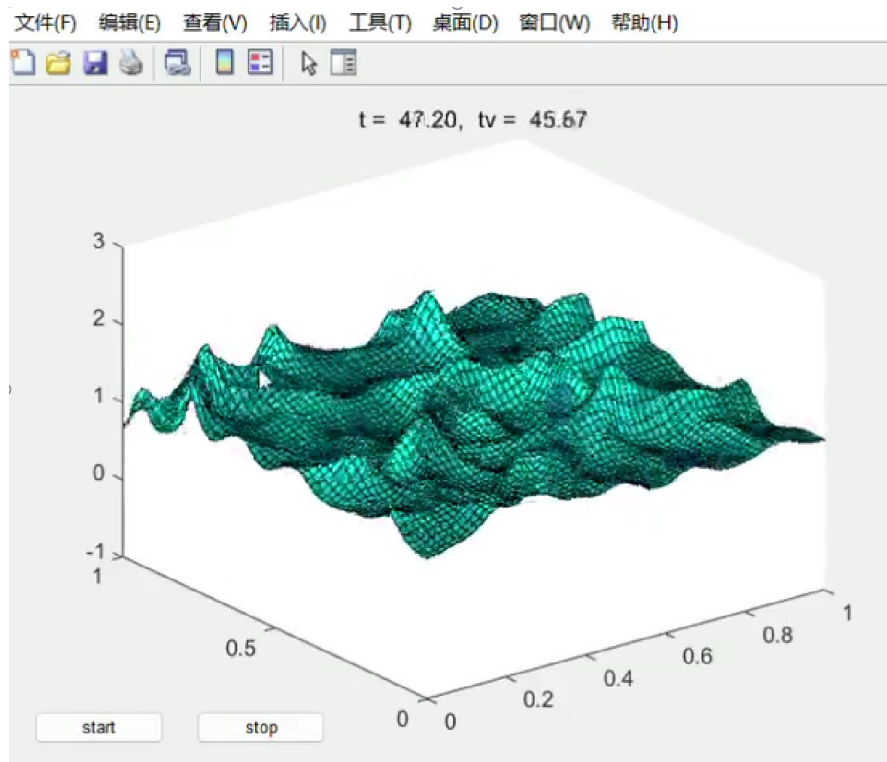


Figure 1: Wave wave model

3.2. MPPT solar charge controller model

The input of solar radiation should be modeled first, in order to study the output of photovoltaic panels. The combination of step functions with different amplitudes is used to fit the change of solar irradiance in this paper. The solar irradiance fitted by the step function changes according to the time period and is used as the input of the photovoltaic power generation panel in the simulation model as time goes by. The change of the function is recorded in seconds, in order to better observe the change of power in the oscilloscope. The solar irradiance test function is shown as follows:

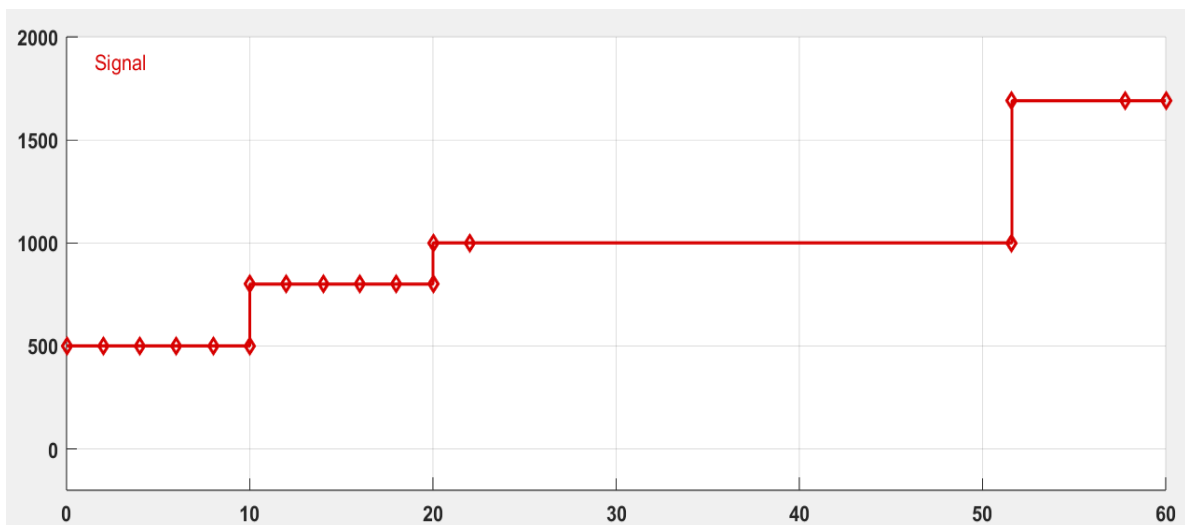


Figure 2: Solar irradiance test function

After the above irradiance signal is input into the photovoltaic panel, under a certain temperature condition (15° as shown in the figure), the output is connected to two subsystems, the Perturb and Observation method and the Battery Charging Control, and the step-down conversion circuit is connected at the same time. In the MPPT Solar Charging Controller system, the input quantity is transformed to output PWM signal, and the MOSFET in the buck conversion circuit is controlled on and off.

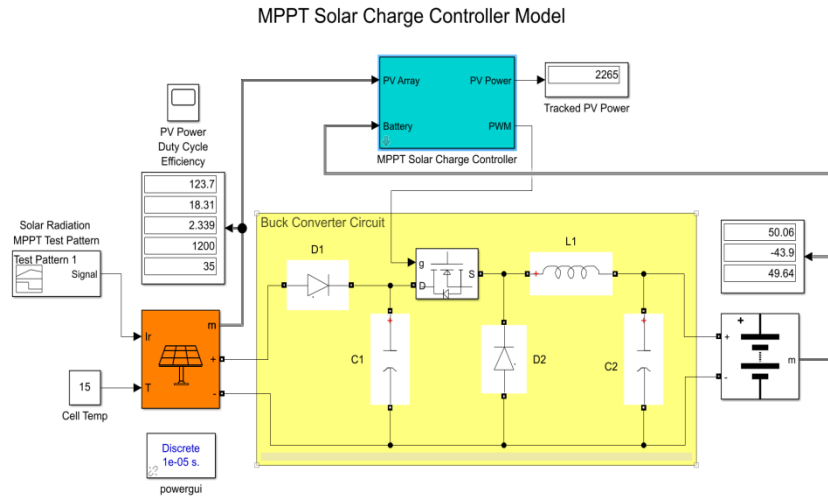


Figure 3: MPPT solar charge controller model

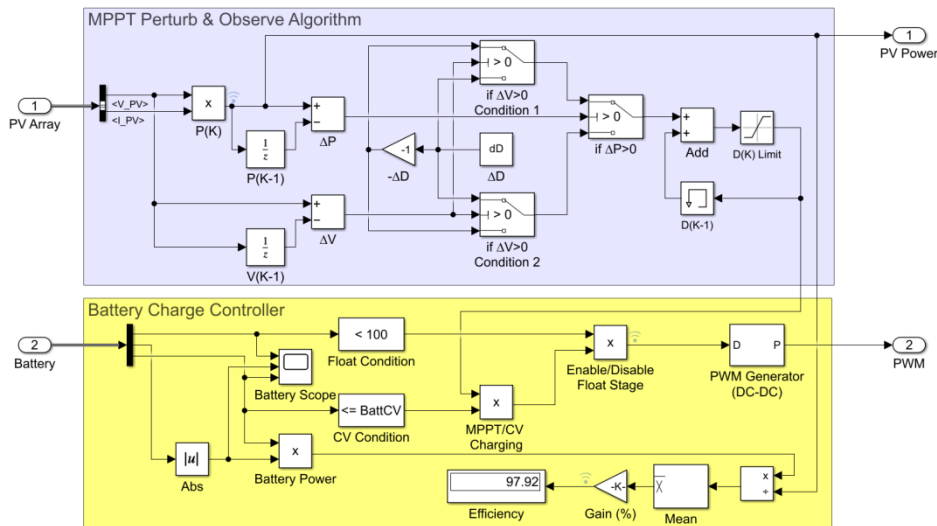


Figure 4: MPPT perturb and observation algorithm and battery charge controller model

The maximum power point tracking technology using P&O algorithm has achieved good tracking effect, as shown in the figure below:

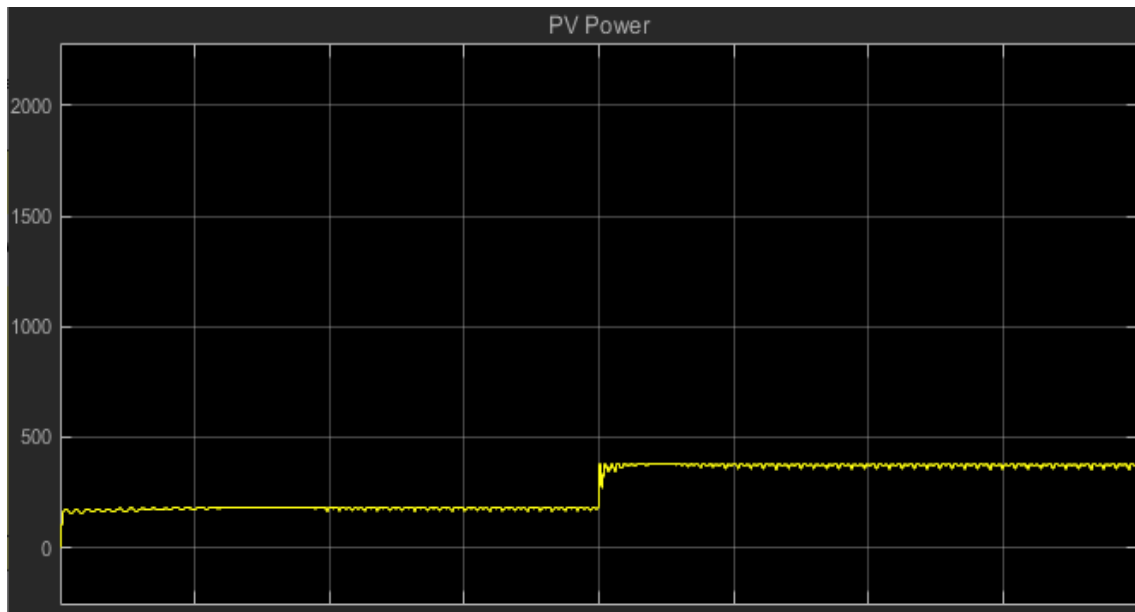


Figure 5: Simulation results of maximum power point tracking

4. Results of maximum power prediction

The core of MPC control in this paper is to predict the irradiance change in the next period, and then according to the predicted results, the voltage and current of the photovoltaic panel in the database should be predicted to the input end of the disturbance observation system in advance, and MPPT real-time adjustment and correction. At the same time, because the input is changed in advance, it can reduce the oscillation of power changes caused by sudden changes in irradiance (effectively reducing the overshoot and reducing the transition process).

Irradiance is taken as input and temperature as control condition in this paper, and different maximum power prediction data is obtained by changing the values of both. The following table takes 20° and 25° as examples to record the power prediction data of photovoltaic panels at 1000-1500 irradiance.

It should be noted that the unit of temperature is “°”; The unit of irradiance is “W/m²”; The power unit is “W”.

Table 1: Predicted power data at different irradiance of 20° and 25°

Irradiance Temperature	20°	25°
1000	2018.756	1994.224
1050	2136.832	2087.564
1100	2236.007	2176.015
1150	2335.033	2287.120
1200	2437.344	2390.472
1250	2519.639	2500.078
1300	2651.646	2592.690
1350	2751.272	2694.960
1400	2838.575	2479.314
1450	2955.794	2884.310
1500	2999.749	2938.087

5. Conclusion

A MPC controlled maximum power point tracking technology for offshore photovoltaic power generation is introduced in this paper. The problem is transformed into predicting the output of photovoltaic panels by predicting the irradiance change, and the corresponding voltage and current values in the database are input into the disturbance observation system in advance for power prediction and tracking. Combined with the simulation model at the same time, several sets of prediction data are obtained, which can be used for future analysis and research. The light abandonment loss caused by the climbing limit of thermal power units is optimally solved in this paper, based on the absorption problem of new energy connected to the grid. And the offshore photovoltaic output power is accurately modeled and predicted according to the temperature and irradiance changes, and the photovoltaic power generation data corresponding to different irradiance under different temperatures is recorded. However, the environmental factors considered in this paper are still too few to simulate the real Marine environment to the maximum extent possible. And the voltage and current fluctuate too much, resulting in a large difference in data with the increase of irradiance.

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