International Journal of Hybrid Information Technology
Vol. 9, No.5 (2016), pp. 1-12
http://dx.doi.org/10.14257/ijhit.2016.9.5.01

Structure Design and Operation Strategy of Storage Battery on Paralleling and Independent Controlling in Photovoltaic System

Na Liu[1], Chengdong Wu[1] and Cailian Gu[2]

[1]*Northeastern University, Shenyang, China*
[2]*Shenyang Institute of Engineering, Shenyang, China*
lna2005_12@126.com

Abstract

The charging and discharging control and management of the energy storage battery are the key links to influence the performance and the service life of the battery in photovoltaic system. According to the inherent characteristics of power terminal of photovoltaic power generation system, this paper designs a control operation mode of a paralleling and independent controlling structure, uses charging and discharging controlled strategy by time-sharing grouped , combines the constant current charging, pulse charge and floating charge trickle charge. The main features of the integrated control strategy method is capable of more efficient utilization intensity of solar radiation, more reasonable control of charging storage energy system. According to the improvement of the structural design of the existing project 100KW photovoltaic engineering power system, and observation and analysis about a large amount of data, the charging effect is obviously improved compared with the former system.

Keywords*: paralleling and independent controlling structure; charging and discharging, pulse charge; storage battery*

1. Introduction

Storage battery has more and more promotion and the application in AC and DC power system, especially plays a crucial role in the construction of wind and solar generation system and construction of micro grid system [1].From the use of storage battery, the main factors affecting the service life of the battery are: thermal runaway, overcharging, over discharging, in the low state of charging for long term and single parameter differences [2]. Compared with the conventional field of application of photovoltaic system, the frequent times of batteries that charge and discharge, the large volatility, randomness and limitation coming from the energy source terminal are difficult to meet the charging requirements of storage battery standard. Seasonal changes of light and continuous overcast and rainy days are easy to cause the depth of discharge energy storage battery, which make it hard to get fully charge in short-term after complete discharging and make it in a low SOC for a long term. Visibly, improper usages about energy storage batteries will shorten the battery life in photovoltaic systems and make the energy storage batteries become the easiest part [3].

The reference[4] is about maximum power point tracking (MPPT) of the traditional constant current, constant voltage and three stage floating charging control strategy used in a photovoltaic system ; Reference [5] uses the control strategy of two stage variable current charging and constant voltage charging; Reference [6] shows that pulse charging can reduce outgassing rate during the battery charging process , effectively eases and even eliminates the polarization response of battery, increases the battery acceptable charging current and charging efficiency, and can prevent or repair battery vulcanization crystallization; Reference[7] proposed a charge equalization circuit with inductor

ISSN: 1738-9968 IJHIT

symmetrically distributed ,achieved a rapid dynamic transfer of energy in the battery and made up un-uniformity of battery ;Reference [8] in allusion to the power unbalance intra-micro grid and the wide fluctuation of DC bus voltage due to unstable output of DC micro resources in DC micro grid, proposed an improved automatic charging and discharging control strategy for the energy storage system, in the DC micro grid system composed of photovoltaic array and energy storage system, the energy storage system can be switched among charging, discharge and idle modes, and the damage of the battery caused by the frequent switching over between charging and discharging modes due to ordinary fluctuation of DC bus voltage can be avoided.

Most of the references have done a deep study on the battery charge and discharge control method, but did not really combined with the special nature of photovoltaic power generation in space and time. Charging method is important, but the need of effective input energy source is important, too. Based on the above technical background, the paper improved the intervention structure of the battery in photovoltaic power generation system, and brought forward the technology idea of parallel–and independent controlling structure, combined with the change of solar irradiance, practiced control mode of battery group by period and packets, used the charging control strategy of phase constant current charging, pulse charging and trickle charge. Through the structural transformation of the existing project 100KW photovoltaic engineering power system, after examination and verification of actual data, the method is feasible, and it can improve the working efficiency and life of lead-acid battery in the optical power generated under practical conditions.

2. Photovoltaic Power System Structure

100 kW photovoltaic power generation system is composed of a PV array and storage battery and control inverter, which can connect grid through public point P_{line}, can also be used as independent net system to supply power. Its core part is inverter control which can control the bi-directional scheduling of optical storage energy, meanwhile can realize the battery charging and discharging control (as in Figure 1).

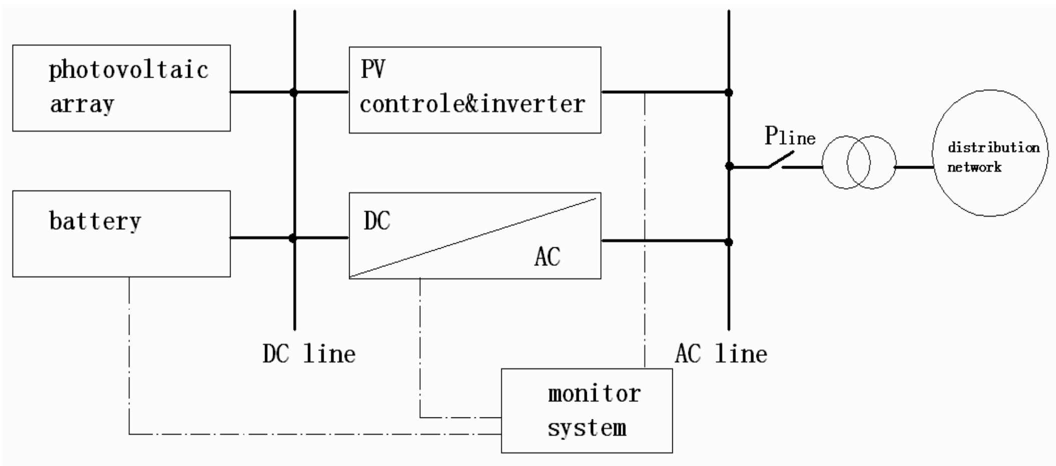

Figure 1. Photovoltaic Power Generation System Structure Diagram

3. The Charging and Discharging Characteristics of Energy Storage Battery

According to the difference of energy storage principle in the energy storage technology field, energy storage technology can be divided into electrochemical energy storage, magnetic storage and mechanical energy storage, electrochemical energy storage mainly included sodium sulfur battery, lithium ion battery, lead-acid batteries and nickel metal hydride batteries, magnetic energy storage mainly included superconducting magnetic energy storage and super capacitor energy storage, mechanical storage mainly included flywheel energy storage, pumped storage, compressed air energy storage, *etc*., all kinds of energy storage batteries are respective advantage in the different application field [9].

Take the photovoltaic power generation as the representative in research of the renewable energy system technique, sodium sulfur battery, lithium ion battery and lead-acid battery have been mainly research and application with their advantages of high energy conversion efficiency and high power density , furthermore, the lead-acid battery has been used more widely with its advantages of mature technology and low cost, this paper takes the lead-acid battery which has been used widely as example, analyses the charging and discharging characteristics and the influence factors of the battery performance and life.

3.1. Characteristics of Lead-Acid Battery Charging

The battery's charging characteristic curve is measured at 25 temperatures and scaled (6.75v constant voltage charging), as shown in Figure 2. Charging curve usually has 3 points.

3.1.1. The Charging Current Curve

At the beginning stage, the charging current is a constant value. As the hydrogen ion and water is losing, battery energy storage capacity decreases and the battery capacity recovers and the charging current decreases gradually. When the battery is almost full, charging state turns to float.

3.1.2. The Charging Voltage Curve

In constant current charging stage, the battery voltage increases faster, known as the boost charge; when the constant current charging is finished, the voltage of the battery is basically unchanged, called the constant voltage charging; in constant voltage charging stage, the battery current gradually decreases, and finally tends to zero; at the end of constant voltage charging stage, it turns into the floating charge to prevent the battery self-discharging.

3.1.3. Charging Capacity Curve

In the constant current charging stage, the capacity of the battery is basically linear growth; in the stage of constant voltage charging, capacity growth is slowed. When constant voltage finishes charging, capacity returns to the basic 100%. Transferred to the floating charge, the capacity is no longer obvious growth.

3.2. Discharging Characteristics of Lead-Acid Battery

The discharging characteristics of lead-acid battery is a group of curves, see Figure 3. In a certain environment temperature (Figure 3 is 25℃), with the difference of discharging current, it has the different discharging curve. Discharging curves can be seen by the following characteristics.

3.2.1. The Capacity in the Process of Lead-Acid Battery Discharging

The capacity is related to discharge current of the battery. After calibration of discharge standard, it is a determination of comparable value.

3.2.2. The Initial Phase of the Discharging

The moment the terminal voltage in the initial phase of the discharging is converted the charging state into the discharging state, the charge near the plates quickly releases. After the part of charge recombination, the charge that is far from the plates needs to be gradually transported to near plate and released.

3.2.3Termination Voltage

As the battery capacity is limited, with prolonging the time of discharging, the battery terminal voltage will eventually decline inflection point, which is called the termination voltage point while security working. The inflection point curve is of the steep downward trend in its voltage till the end point of the discharge curve, which is called minimum termination voltage, which means it will cause the battery permanent failure in the state of discharge voltage below this curve.

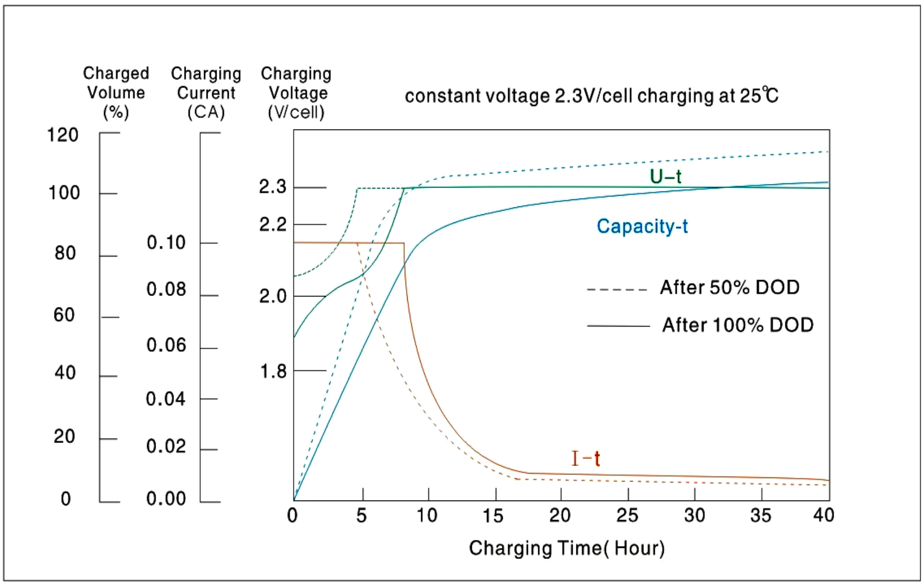

Figure 2. Battery Charge Curve

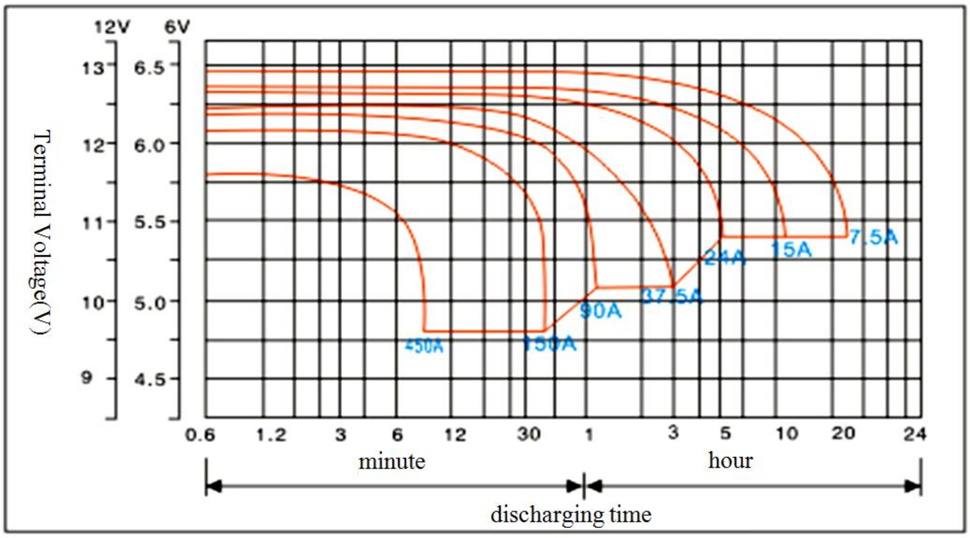

Figure 3. Battery Discharge Curve

3.3. Battery Life Influence Factors

It is the key to control the charging and discharging of the battery and overcharging and over discharging will cause the battery life not to be up to the normal cycle, and long-time low-energy battery causes capacity declined and even the battery collapsed in a short time.

3.3.1. Overcharging

In the state for a long time charge, anode for oxygen evolution reaction, water is consumed, the increase of H^+, which leads to increase acidity near the anode and grid become thinner because of accelerated corrosion so that the battery capacity is reduced. At the same time because the water loss intensifies, it leads to the battery has the danger to dried up, thus affecting the life of the battery.

3.3.2. Over Discharging

Over discharging of the storage battery mainly occurred after the failure of the AC power and the storage battery was in a poor state to run for a long time. When the battery voltage is too low due to excessive discharging, it will have a large amount of lead sulfate from internal battery adsorbed to the surface of the cathode battery to cause "sulfate" phenomenon. Lead sulfate is an insulator. More sulfates formed on the cathode, the greater the inner resistance of battery was. The battery charging and discharging performance is poor and the service life of the battery is shortened.

3.3.3. Long-Term Floating Charging

In long-term floating charging state, it will cause the battery anode plate passivation while only charge but not to discharge, and result in battery internal resistance increasing, capacity decreased sharply, service life shortly.

3.3.4. Off-Capacity

When battery are lack of capacity seriously, in a floating state, terminal voltage is normal, temperature display normal, no leakage, but can short time collapse under the loss of power or unexpected low AC voltage. In addition, in the overcharging station, there may be the hidden trouble of explosion and combustion, and still a certain degree of environmental pollution.

In the photovoltaic power generation system, the charging current from the solar light radiation, according to the time variation of the solar radiation during twelve hours(AM6:00-PM6:00),as known, irradiance may reduce 1/2 before AM10 and after PM15.For a total constant capacity of storage battery, the charging time of daily trickle charge or almost invalid current accounted for 2/3,the battery is in the recharging stage after cycle discharging, it will cause the battery anode plate passivation and reduce battery performance and life if being the trickle charge state in a long time.

4. Structure Design and Operation Strategy of Storage Battery on Paralleling and Independent Controlling

4.1. Structure Design

Adopting the mode of paralleling and independent controlling to the battery groups, based on reaching the requirement to the charging voltage, pieces of battery controlling on paralleling are independent. According to the solar illuminance radiation variation trend with 30 minutes, this mode can adjust the battery to input and exit, used for maintaining the best charging current consistently during the constant current charging, the pulse charging and trickle charge stage. Because of the relation between the discharge current size and the customer load, at the time of discharging, in order to ensure the consistency of the battery, concentrated discharging can be directly used. Charging and discharging system scheme of storage on the paralleling and independent controlling as follows Figure 4. The diode is mainly anti and isolation effect in the graph, because of long time online, should choose the high quality such as 1000V/300A high power diode. After solving the problem of heat dissipation, it can ensure the long-term stable and reliable working.

Through the QF11 and QF1n (QF11 may be circuit breaker or controlled rectifier tube device of semiconductor silicon) control each parallel battery input and exit, n group batteries are isolated by the diode, n group of parallel batteries are maintaining independent and mutual influence, it ensures that the battery can be charged in balance, at the same time the groups of batteries can be mutually redundant backup, when one group of batteries BT1 failure, it automatically can be exited the system, other a battery BTn can be complementary. BTn battery voltage will not reverse filling to fault battery BT1, moreover, battery BT1 is working online when the set of BT1 voltage is higher than BTn, and battery BTn is back-up, while battery BT1 needs maintenance, disconnect switch QF11 and the switch QF21, and close switch QF31 (bypass switch) to discharge; when battery BTn needs maintenance, disconnect switch QF1n and switch QF2n, and close switch QF3n (bypass switch) discharge.

Similarly, when discharging, through breaking and connecting switch QF21 to QF2n control centralized discharging or dispersed discharging.

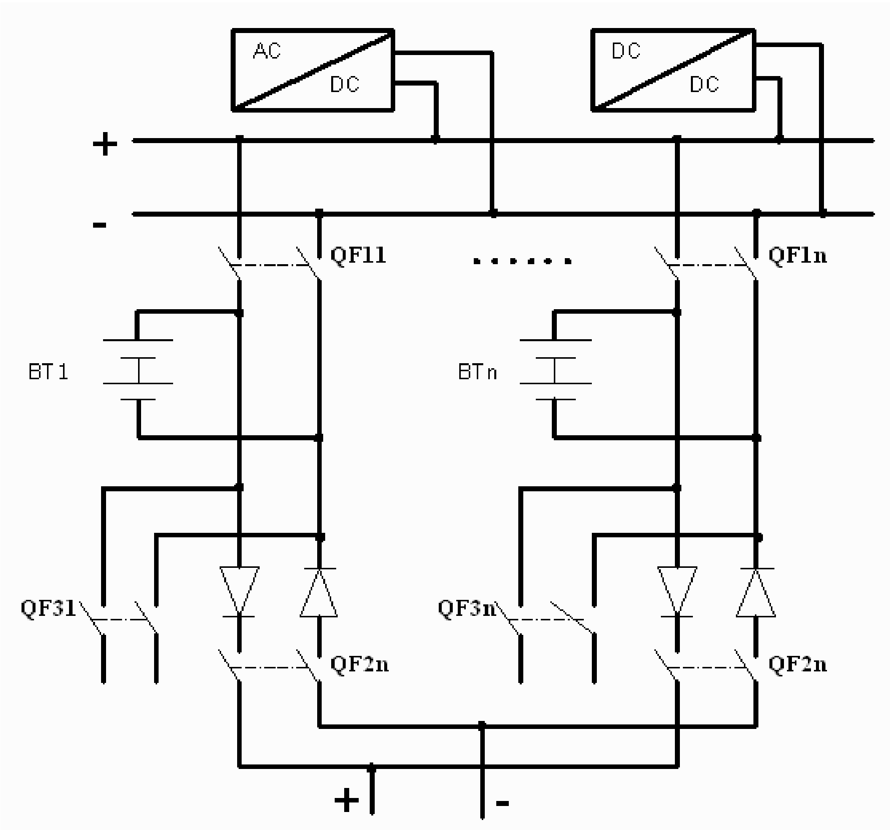

Figure 4. The Energy Storage Structure on Paralleling and Independent Controlling

4.2. Operation Strategy

The output Parameters of PV array can be defined using the following model [10-13]:

$$T = T_{air} + K \cdot S \tag{1}$$

$$\begin{cases} \Delta T = T - T_{ref} \\ \Delta S = S - S_{ref} \end{cases} \tag{2}$$

$$\begin{cases} I'_{sc} = I_{sc} \dfrac{S}{S_{ref}} (1 + \alpha \Delta T) \\ I'_{m} = I_{m} \dfrac{S}{S_{ref}} (1 + \alpha \Delta T) \end{cases} \tag{3}$$

$$\begin{cases} U'_{oc} = U_{oc} \times (1 - c\Delta T) \times \ln (e + b\Delta S) \\ U'_{m} = U_{m} \times (1 - c\Delta T) \times \ln (e + b\Delta S) \end{cases} \tag{4}$$

In the formula:

T expressed as the actual radiation battery temperature intensity and ambient temperature, ℃; T_{air} expressed as ambient temperature,℃;K take0.03℃·m^2/W; T_{ref} expressed as battery temperature under standard conditions,25℃; S expressed as gross underestimates of radiation intensity/m^2; ΔT expressed as discrepancy between actual value of the battery temperature and battery temperature under standard condition; ΔS expressed as discrepancy between actual value of radiation intensity and value of radiation intensity under standard condition; S_{ref} expressed as value of radiation intensity under standard condition,1000W/m^2; E expressed as the base of natural logarithm,take2.71828;α expressed as compensation factor, it's value take0.0025℃;b expressed as compensation factor, it's value take 0.0005/℃; c expressed as compensation factor, it's value take 0.00288/℃; I_{sc} expressed as the short-circuit current under standard condition; I_m expressed as optimal working current under standard condition; U_{oc} expressed as open circuit voltage under standard condition; U_m expressed as the optimal working voltage under standard condition; I'_{sc} expressed as the actual value of the short-circuit current; I'_m expressed as the actual value of the optimal working current; U'_{oc} expressed as the actual value of open circuit voltage; U'_m expressed as the actual value of the optimal working voltage.

Supposing to divide the micro grid system into γ parallel groups, each parallel group is composed of m battery connected in series, and m=U_E/12v, each battery capacity is C, then the series battery C_{bat}=Mc, take γ (k) as parallel battery group number, in the constant current charging stage, by formula (3) to get the optimal output current of PV array at time t, then select the maximum rechargeable battery group numbers (γ (k)):

$$I_{cha} = 0.1C \cdot \gamma(k) \tag{5}$$

$$\gamma(k) = \frac{I'_m(t)}{C_{0.1}} = \frac{I_m(t) S(t)}{C_{0.1} S_{ref}(t)} (1 + \alpha \Delta T) \tag{6}$$

I_{cha} expressed as the value of battery charging current; $C_{0.1}$ expressed as battery charging rate0.1C.

When the battery capacity reaches 60%-70%, the second stage (pulse constant current charging) is beginning. Design of PWM pulse generator in the structure of the main circuit of the energy storage battery, compare with U_{cha} and U_{ref} continuity and produce the corresponding duty ratio, and generate corresponding PWM signal by the triangular carrier, make value of U_{cha}(charging voltage) maintain at U_{ref} (reference voltage),it means to decreaseΔD(ΔD is duty cycle step)when U_{cha} is higher than U_{ref},on the contrary, raises ΔD.Battery capacity will be saturated when the duty ratio decreases to 10% .And system enters into trickle floating charging stage, using weak current to maintain in the saturated state, which is named the maintenance of storage battery.

5. Test Results and Analysis

Total battery capacity photovoltaic system configuration storage is 48V/12000Ah, battery of the improved system will be divided into 4 groups of parallel, and allocated to 4 groups of segment switch (QF11,QF12,QF13,QF14)and(QF21,QF22,QF23,QF24),the new system related parameters setting: I_{cha}= 1200A, r(k)=4,$\eta = 0.85$,U_{ref}=50.2V.Real-time tracking and recording on the battery charging process parameters, battery capacity and temperature of the system before and after the improvement are in progressing, and forms the curve as follows Figure 5- Figure 7, Table 1 and Table 2.

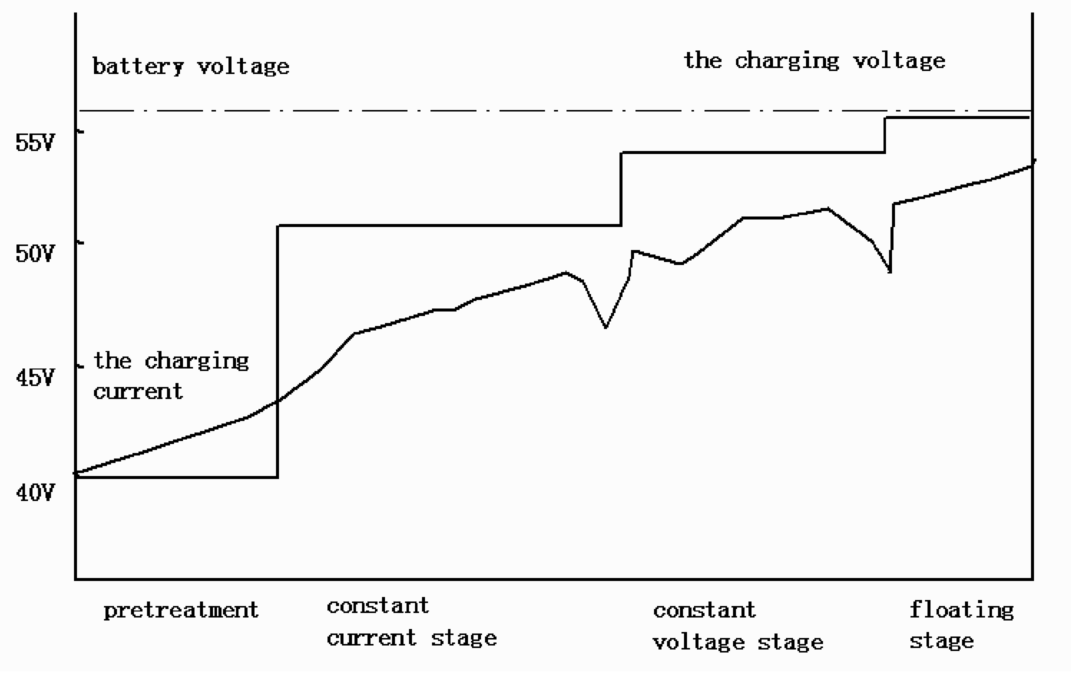

Figure 5. Effect of Charging Curve before the Improvement

From Figure 5 shows, by the impact of energy source fluctuation, the charging current did not reach the expected effect of the steady flow, and shows in Figure 6, by changing to connection structure of storage battery based on paralleling and independent controlling, it makes charging voltage curve rising in a linear and stable way in constant current region, until it reaches a constant voltage threshold, then the pulse charging mode starts. In the pulse stage, charging source charges into battery intermittently with constant voltage charging. The charging time is becoming shorter and shorter and the stop charging time is becoming longer and longer. That means when pulse cycle is increasing longer and longer and duty ratio is becoming smaller and smaller. When the duty ratio is lower than 5% to l0%, the battery will enter into trickle floating stage.

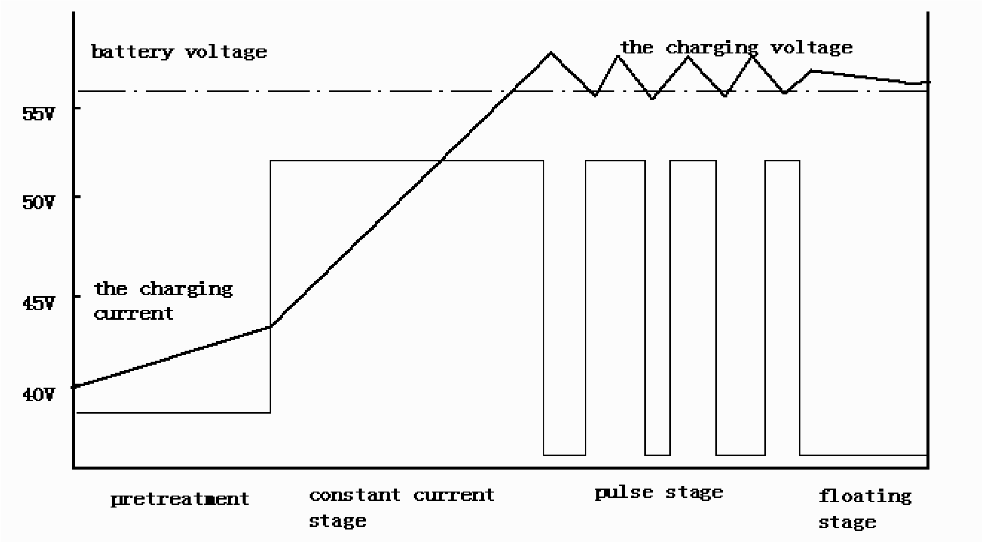

Figure 6. Effect of Charging Curve after the Improvement

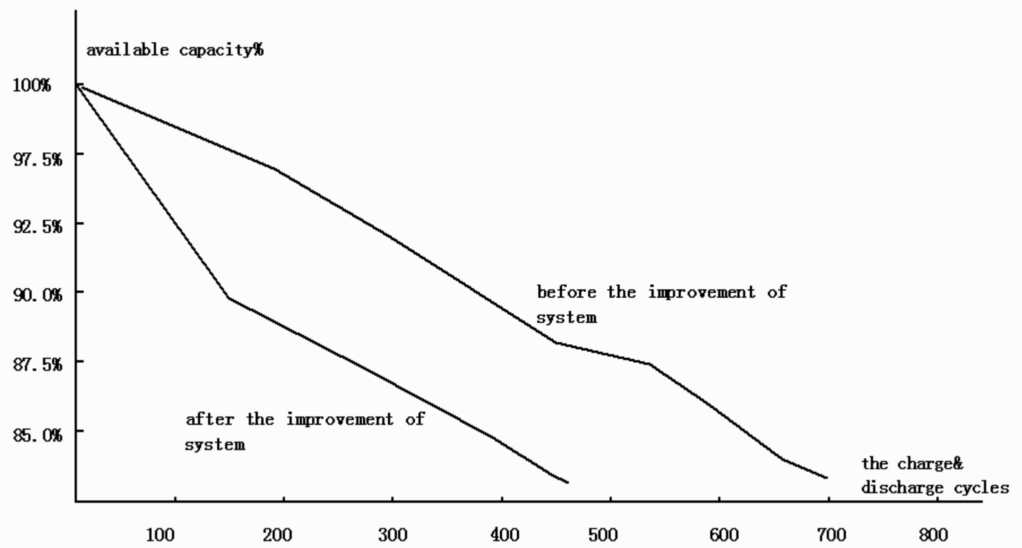

Figure 7. Capacity Curve Before and After the Improvement

Table 1. Charging Time at Different Temperatures

charging temperatures(℃) charging time(hour)	0	5	10	15	20	25	30	35	40
charging system before the improvement	20	17	16	15	14	13	12	11	10
charging system after the improvement	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5

Table 2. Available Capacity at Different Temperatures

charging temperatures(℃) available capacity (Ah)	0	10	15	25	30	35	40
charging system before the improvement	10300	11023	11056	11077	11086	11090	11125
charging system after the improvement	10300	11258	11320	11690	12000	12252	12850

Through the experiment of the cycle times and charging and data processing for the energy storage system structure before and after improvement, it can be seen from Figure 7. Under the same condition of cycles times, contrasted the storage structure before the improvement with the storage structure after the improvement on battery available capacity, the latter was significantly higher than the former. From Table 1 and Table 2 it can be seen that the effect of the improved charging time of the battery is basically not affected by temperature changes, and the available battery capacity of two systems both all increase as the temperature increasing. But obviously the improved battery system of the available capacity is higher than the unimproved system. Because of the storage battery has been effectively supplement with the energy, and combines with pulse charging intermittent control, the battery capacity can be effectively activated when charging, thereby maintains the initial capacity of battery better.

6. Conclusion

Combined with changing of solar energy light radiation, this paper carried out a technical renovation on storage battery structure of photovoltaic power generation system based on paralleling and independent controlling, effectively avoiding the problems of the battery less-charging due to photovoltaic output fluctuation, and because of using the method of intermittent pulse charge control after the constant current charging stage, it improves the battery's charging efficiency, effectively activates the battery capacity, greatly maintains the cell performance. Through the test of the data validation, the method is feasible that adopted on the charging structure of paralleling and independent controlling combining with the charging strategy of constant current and pulse charging and trickle flow charging. And the method can be applied to the micro grid system. However, due to micro power structure is complex in the micro grid system, including photovoltaic power generation, wind power, diesel power generation and hybrid energy storage battery, grouping controlled structure will be good for the stability of micro grid system ,maintenance and use of energy storage battery.

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Authors

Na Liu, a PhD. student of Northeastern University, Specialize in pattern recognition and intelligent system at college of Information Science and Engineering, Shenyang, China, Her main research fields are renewable energy technology, micro grid system and intelligent power grid construction and management.

Chengdong Wu, Vice president of Shenyang Northeastern University of college of Information Science and Engineering and director of the Institute Artificial Intelligence, professor, doctoral tutor. He has long been engaged in automation engineering, artificial intelligence and robot navigation teaching and research, he is an expert of Chinese modern artificial intelligence and robot navigation, and he is also a special allowance of the state council.

Cailian Gu, a lecturer of electrical engineering at Shenyang Institute of Engineering, Shenyang, China, Her main research interests are power system reconfiguration, electric distribution system, and demand management.

