Design and Implementation of Solar Portable Maintenance Power Box

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Abstract. In order to solve too long maintenance power line and time-consuming in outdoor of substation, and when many maintenance team are working, wiring is confusion, which is easy to create security risks and other problem, a solar portable maintenance power box which using electric/photoelectric complementary technology, is designed from appearance structure, the grid/solar input module, control circuit of battery and inverter. It is tested by using simulation of Matlab/Simulink. Finally, the contrast test is proved to improve efficiency and reliability of maintenance in the substation.

1. Introduction
The maintenance power box is an essential electrical maintenance equipment in the field of substation. The traditional power box has a lot of disadvantages: 1. the line is too long to be complicated; 2. when operating location is transferred, the line should be recollected; 3. we need to connect two power boxes between two remote electrical devices in the substation; 4. when several maintenance professionals are simultaneously overhauled in the field, the complicated power wiring leads to confusion, and the site risk of safety control is increased; 5. when the whole substation is powered by power failure, the power supply of large generator is adopted, and its power supply quality such as frequency and voltage is unstable, which is likely to cause damage to the test equipment.

In recent years, photovoltaic power generation has been widely used in power system grid-connected and photovoltaic lighting [1], but the application of power supply in substation maintenance test is few. The paper [2] proposes a multifunctional solar energy mobile power source, which is studied from the voltage stabilization module, overcharged overcharge protection and output port circuits, and output port is mainly oriented to LED lighting, mobile phone, MP3, radio and other digital products. The paper [3] is designed from the aspects of external structure, energy flow and control circuit, which mainly faces the power supply and demand of heat supply in the island area. The paper [4] has designed a photovoltaic-electrical complementing system based on the maximum power point tracking technology of the variable step long voltage free detection. The paper [5,6] put forward the ungraded voltage stabilized dc power supply based on solar energy, which can meet the needs of mobile electronic equipment and various test instruments. The paper [7] put forward a kind of high
efficiency, safety and reliability of solar mobile power supply design method, which can effectively solve small solar mobile power and undercharged problem.

In the paper, a solar portable maintenance power box is developed, which is designed and simulated from four aspects, such as appearance structure, input module of electric/photovoltaic, battery control circuit and output circuit of inverter, and it is applied to the substation, which can effectively solve the power supply requirements of workers in the operation field and improve the maintenance efficiency.

2. Design of the Appearance Structure of Solar Portable Maintenance Power Box
The appearance structure design is shown in figure 1. It has two parts: a) portable mobile power box, b) battery panel structure and solar charging interface. The line and battery unit in the portable portable power supply box are located on the top and bottom of the box respectively, and the mobile pulley is installed at the bottom of the moving frame. When solar energy charging panels are in operation, absorbing light energy is converted into electricity and stored in a battery cell. The external output stability of 220V AC is mainly controlled by the control circuit and output circuit of inverter in the cell structure.

![Figure 1. The external structure of solar portable maintenance power box.](image)

3. Design of the Grid/Photovoltaic Input Module
The battery unit consists of electricity and solar. The photovoltaic is provided by the solar panel, while the municipal power is the 220VAC in the substation, as shown in figure 2. In the sunny environment, photovoltaic power generation can be directly used to provide charging power to the battery. In the rainy weather, the battery can be charged by 220VAC in the maintenance of substation. The DC input
power supply of the inverter is provided by the battery, which can meet the demand of the power supply of the measuring instrument in the substation.

Figure 2. The overall structure of energy.

3.1. Input Module of Photovoltaic
The design is shown in figure 3. The module was firstly passed through the rectifier diode 1N5408 rectifier, then filtered by RC circuit, and finally obtained 48V DC voltage through two series voltage stabilizer diode 1N723, which was charged by the battery overcharge protection circuit. In figure 3, the switch K1 is the photovoltaic/grid switching switch. When it closes, the photovoltaic input module is selected.

Figure 3. Power supply module of solar.

3.2. Input Module of Grid
The design is shown in figure 4. The module is passed through a charger (step-down transformer and rectifier bridge circuit) to rectify the 220V to 96V, and then the RC filter circuit is sent to the LM7824 to output a stable 48V DC voltage, which is then further filtered through the RC filter circuit and then passed through the protection circuit to charge the battery. In figure 4, the switch K1 is a photovoltaic/grid input switch, and when it is switched to the grid module, the red light are on.

Figure 4. Power supply module of the grid.
4. Control Circuit of Battery

Control circuit of the battery mainly realizes the charge and discharge protection of the battery, including overcharge and overdischarge protection circuit[8]. Overcharge protection circuit is shown in figure 5. The photovoltaic/grid input module is charged to the battery by means of a normally closed contact J11 of the contactor J. When the battery voltage in the overcharge protection circuit is larger than the overvoltage value, the coil JA1 of contact J is engaged, and the normally closed contact J11 is open. The photovoltaic/grid input module is disconnected from the battery which realizing overcharge protection. Overdischarge protection circuit is shown in figure 6. When the battery voltage is larger than the undervoltage, the contact coil JA2 is closed, and the normally open contact J22 is closed, and the inverter is supplied with DC power. When voltage of the battery is lower than the undervoltage, the normally open contact J22 is regained to the open state, and the battery is stopped from supplying DC power to the inverter.

5. Inverter Circuit

Because the equipment used by the maintenance workers in the substation generally adopts 220V single-phase AC power, the inverter is composed of single phase whole bridge PWM inverter circuit, boost circuit and low-pass filter circuit [9], as shown in figure 7.
The amplitude of the voltage $U_0$ waveform $u_0$ has been analyzed, and the fourier series decomposition is obtained first [10].

$$u_n = \frac{4U_d}{\pi} \left( \sin \omega t + \frac{1}{3} \sin 3\omega t + \frac{1}{5} \sin 5\omega t + \frac{1}{7} \sin 7\omega t + \cdots \right)$$  \hspace{1cm} (1)

In order to obtain 220V single phase AC voltage, it must be added a boost transformer after the single phase whole bridge PWM inverter circuit. The transformer ratio is set as $K$ ($K > 1$), $K$ is 5.1 [11], $u_0$ and $u_1$ are the primary and secondary voltage of the boost transformer, and $U_d$ is the DC voltage of the battery.

$$u_i = \frac{20.4U_d}{\pi} \left( \sin \omega t + \frac{1}{3} \sin 3\omega t + \frac{1}{5} \sin 5\omega t + \frac{1}{7} \sin 7\omega t + \cdots \right)$$  \hspace{1cm} (2)

Therefore, effective value $u_1$ can be obtained.

$$U_1 = \frac{20.4}{\sqrt{2}} \frac{U_d}{\pi} = 4.59 \ U_d$$  \hspace{1cm} (3)

The features of SPWM signal: the switching frequency is often far larger than the base frequency. The harmonic is very large, so the filter has a higher requirement for the pass band flatness and the resistance band decay rate. A better filter is the second low pass filter of butterworth, which has the characteristic of the largest flat response and drag reduction in the lead band, and it has to be filtered to get sine AC voltage.

6. Test and Result Analysis

6.1. Circuit Simulation and Analysis

In order to verify validity of the circuit, the Matlab/Simulink simulation model of battery cell is constructed, as shown in figure 8. In figure 8, PV is a photovoltaic cell model, and Universal Bridge2 arms is a single phase whole bridge PWM inverter model. The whole simulation adopts ode23tb algorithm. The simulation results are shown in figure 9.

Figure 8. Single phase whole bridge PWM inverter of the simulation model.
Figure 9. Waveform of the simulation.

It is shown from Figure 9 that that DC voltage output by the photovoltaic module and the grid module still contain a small number of high harmonics, and the output DC voltage which controlled by the battery control circuit is stable to 48V, and the output voltage is a sine wave with a magnitude of 311V.

It is proved that the circuit can meet the demand of stable output of 220V AC voltage.

6.2. Physical Test Analysis

A solar portable maintenance power box was built, as shown in Figure 10. The battery, which uses 20AH, can meet the maintenance of 2 days basically. Its’ weight is 20kg, and the average person can carry it easy. Cells integrated the leakage breaker, fuse, charging insurance, cooling fan, and double open switch. It has two charging modes of the solar and grid charging. The commonly used electrical components are integrated into the electric pool unit, which can be used to meet the daily needs.

Figure 10. A solar portable maintenance power box.

Compare the output voltage data of the traditional box with the solar portable maintenance power box in the annual maintenance of the substation, and the test results are shown in table 1.
Table 1. Comparison of the test results.

| Project                        | Traditional box          | Solar portable maintenance power box | AC output voltage (V)/voltage fluctuation. |
|--------------------------------|--------------------------|--------------------------------------|-------------------------------------------|
| 35kV Guan yuan substation      | 198/10%                  | 220.5/0.23%                          |                                           |
| 110kV Tao yuan substation      | 219/-0.45%               | 220.3/0.14%                          |                                           |
| 110kV Re shi substation        | 222/0.9%                 | 220.6/0.27%                          |                                           |
| 220kV Tai zimiao substation    | 221/0.45%                | 220.2/0.09%                          |                                           |
| 220kV Cai jixi substation      | 221/0.45%                | 220.5/0.23%                          |                                           |
| 220kV Tie shan substation      | 224/1.8%                 | 220.8/0.36%                          |                                           |

Note: Total station blackout maintenance have used diesel generator for traditional maintenance power box in 35kV Guan yuan substation

In addition to total station blackout maintenance cause the output voltage fluctuation of the traditional box to 10% by diesel power generation, the AC voltage fluctuation at the time of other substation is within the tolerance of voltage fluctuation (+2.5%). The output voltage is acceptable, but the accuracy of solar portable maintenance power box is higher. Through the use of the box in the field, the test such as the outdoor 110kV TA test, breaker on and off switch test can be used for power supply. It has been found that the power supply for full loads can last 16 hours, which can meet the requirement of ordinary maintenance work.

7. Conclusion
The paper design solar portable maintenance power box from four aspects, such as appearance structure, grid/solar input module, battery control circuit and inverter respectively. Its stability can be solved effectively through Matlab/Simulink construction and simulation. It can effectively solve the problem which is long maintenance line, time consuming, and security risk of field wiring confusion. It's very practical.

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