Power supply system for No. 0 station of substation based on photovoltaic energy storage

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Abstract

As a substation's power reserves are generally powered by a power terminal or a superior station, only power supply faults within the station can be addressed. To address this issue, a photovoltaic power storage system is proposed for substation usage, focusing on the mathematical model of photovoltaic cells, the application of a bidirectional inverter in the energy storage system, and the energy control logic of a photovoltaic power supply. The proposed model was implemented in a MATLAB/Simulink environment for the simulation of energy conversion at various operating conditions. The results indicated that the proposed system design using photovoltaic energy storage is effective with addition mode power supply substation and can improve the overall reliability and safety of the substation's power supply.

Keywords: No. 0 station power supply, photovoltaic battery, energy storage, wind storage system

1. Introduction

A No. 0 transformer is used to improve the reliability of the power supply of a given substation [1] and generally receives its power supply from outside of the station. Most stations introduced outside the station are the same as the superior station of the station or the power terminal of the station. Under this structure, only internal substation power supply faults can be addressed. When the substation cannot supply normal power, e.g., in the case of an overstep trip or station failure, and there is no other backup power supply system available, the accident is enlarged and station No. 0 is changed to lose the reserve function [2, 3]. Accidents occurring at night or in extreme weather further lengthen power outages and increase losses [4, 5]. Currently, accidents are responded to with emergency power supply vehicles [6]. However, these vehicles take time to arrive from their command center, especially in heavily trafficked metropolitan areas.

Therefore, to improve the reliability and security of the power supply of substations, a photovoltaic (PV) power storage system for substation usage is proposed in this work. A set of independent, clean, and intelligent power supply system combined with new energy generation and energy storage is used.

2. Model Description

2.1 System topology structure and component model

The designed power reserve system using a photovoltaic energy storage station based on maximum power point tracking (MPPT) controller consisted of photovoltaic cells, a battery system, a bidirectional inverter from a grid-connected inverter, meter, the integrated application of distributed microgrid

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technology, fast intelligent emergency zero input technology, as shown in Fig. 1.

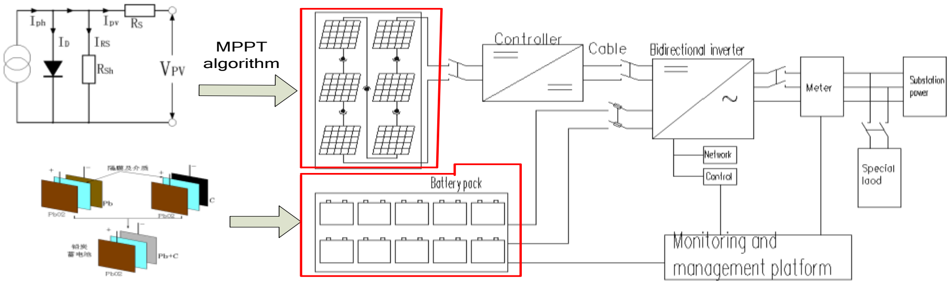

Fig. 1. System topology diagram

2.2 Photovoltaic cells

The photovoltaic cell is a diode stack that is the most basic unit of energy conversion in a wind or solar electricity generation system. According to Kirchhoff's law of current:

$$I_{pv} = I_{ph} - I_D - I_{RS}, \tag{1}$$

$$I_D = I_0 [e^{\frac{q(V+IR_S)}{nkT}} - 1], \tag{2}$$

$$I_{RS} = \frac{V+IR_S}{R_{sh}}, \tag{3}$$

where I_{ph} is the photocurrent, represented by the short circuit current; I_D and I_0 are the total diffusion current and reverse saturation current of the diode, respectively; q is the electronic charge, equal to $1.6*10^{-19}C$, K is Botzman coefficient, equal to $1.381*10^{-23}J/K$; V is the no-load voltage; T is the thermodynamic temperature; n is the fitting coefficient of the diode; and R_S and R_{Sh} represent the series resistance and side-leakage resistance, respectively.

As R_{sh} is high, I_{RS} is very small, almost open-circuit and ignorant. Furthermore, R_s is less than the forward resistance of the diode, which is negligible, and can thus also be assumed negligible. Therefore, (1) can be rewritten as:

$$I_{pv} = I_{ph} - I_0 [e^{\frac{q(V+IR_S)}{nkT}} - 1] \tag{4}$$

2.3 Lead-carbon storage battery

As PV cells can only be used to convert energy during sunlight hours, an energy storage system must be used for power supply during nighttime hours or cloudy days. The energy storage system was designed to store and provide power to the power load when necessary, either via a steady-state or instantaneous large current function to the impact load.

A large variety of batteries are currently available. Composite electrode lead-carbon batteries, due to [], have a better low-temperature starting capacity, charge acceptance capacity, and high-current discharge performance than traditional lead-acid batteries. They provide a charging speed eight times faster than and discharge power three times higher than [] … 3. the life cycle of up to 6 times, charge cycles up to 2000 times; 4. the price high, higher than the price of lead-acid battery recycling, but the life is greatly improved; 5.the use of safety and stability, that can be widely used in various fields of new energy and energy saving. In this study, lead-carbon battery is selected as a unit of energy storage system.

2.4 DC–AC and AC–AC

An integrated two-way inverter scheme using MPPT and including DC–DC and DC–AC transformation was designed to support load, battery energy storage, and on-grid and off-grid PV power access. The implementation of multiple working modes allows for seamless switching between off-grid state and a continuous load.

A comprehensive closed loop control strategy of the outer loop and the inner loop of the current was used. The required input includes the input current and voltage, *I* and U, respectively. The output voltage is then used as an outer loop feedback. After the light storage power generation system, the DC output of the photovoltaic unit is converted into AC through the inverter, and then the grid is connected. The inverter uses a three-phase two-level voltage source transform circuit and an inductor filter to filter the current of the power grid. The output ports of the inverter are connected to the specific load and the grid.

The system was designed such that the electricity generated during daylight hours can be split by the photovoltaic controller between the power grid and charging the battery. When the power grid or PV system is used to charge the battery, the DC–AC converter operates in a rectifying state, i.e., the AC voltage of the grid side is rectified as DC voltage, and the DC voltage is charged by a two-way DC–DC converter to the battery. When the battery is discharged, the DC–AC converter works in a state of inversion, i.e., the DC–DC converter increases the pressure to DC–AC, providing the DC side voltage through the inverse into the AC grid.

The structure with DC–DC and DC–AC has a strong structure, and it can manage the charge and discharge of multi series parallel batteries. Its energy storage system configuration is relatively flexible, and it is suitable for photovoltaic and other intermittent and strong distributed power access. It can suppress voltage fluctuations caused by direct grid connection.

2.5 MPPT algorithm

PV panels can reach between 20% and 25% conversion efficiency in the laboratory with system conversion efficiencies reaching ca. 17%. To generate the maximum amount of electricity under varying loads during operation, an MPPT control module was used to can continuously track the operating conditions necessary to reach the maximum power of the PV system via the following formula：

$$V_{opt} = K_G * \int \frac{dp_{pv}}{dV_{pv}} dt \approx K_G * \int \frac{\Delta p_{pv}}{\Delta V_{pv}} dt , \tag{5}$$

where V_{opt} is the optimal voltage value for the corresponding MPPT, K_G is the proportional gain, Δp_{pv} is the change in power between two running points, and ΔV_{pv} is the voltage variation between two operating points.

A variety of MPPT control strategy algorithms exist, including the look-up table method, curve fitting technique, open-circuit voltage method, and disturbance observation method. Furthermore, intelligent control technology has been introduced into MPPT control systems in recent years. Fuzzy controllers are able to handle nonlinear problems and can effectively control the robustness of the system without an accurate mathematical model. Therefore, a fuzzy controller was implemented. The required MPPT algorithm inputs were the power variation (ΔP_{pv}) and voltage variation (ΔV_{pv}); the voltage value ($\Delta V_{pv, ref}$) is then given as an output. As the power control principle (P_{pv}) is increased, the operating point of power increased and the power (P_{pv}) decreased, corresponding adjustment voltage to the fixed value ($\Delta V_{pv, ref}$). The control equations are as follows:

$$\begin{cases} \Delta p_{pv} = P_{pv}(k) - P_{pv}(k-1) \\ \Delta V_{pv} = V_{pv}(k) - V_{pv}(k-1) \\ \Delta V_{pv,ref} = V_{pv}(k-1) + V_{pv}(k) , \end{cases} \tag{6}$$

where $P_{pv}(k)$ and $V_{pv}(k)$ are the power and voltage, respectively, and the sampling time K is generated by photovoltaic cells. There are thus only two possible power changes: a positive and negative phase change. By rule determination, the voltage setting value $\Delta V_{pv,\,ref}$ can be modified to appropriately increase the power, P_{pv}.

2.6 System efficiency

The system efficiency of an electricity generation system using PV panels depends on the efficiency of each system component. The optical storage system was designed based on a DC coupling system; as such, photovoltaic display mode and the parallel connection of the battery pack in the DC side of the multimode inverter must be considered. The typical efficiency of the components of the battery grid-connected photovoltaic power generation system is given in reference [7], as shown in Table 1.

Table 1. Typical efficiency of the various components in grid power system

Component parts	Cable	Independent photovoltaic controller	Multimode converter	Grid-connected inverter	Battery charging (coulomb efficiency)	Battery charging (time of time)
efficiency	>99%	>95%–96%	>88%–96%	>95%–96%	>90%	>80%

The demand in basic price was assumed as the original load. The wind power forecast and original load are shown as Fig. 3.The prices of purchasing electricity and gas are shown as Fig. 4.

The following system efficiencies were computed as:

a) photovoltaic power transmission efficiency to the power grid or specified load (minimum efficiency for each component):

$$\eta_{pv-SUPPLY} = 95\% * 88\% * 99\% = 82.76\%, \tag{7}$$

b) efficiency of battery power to the power grid or specified load (minimum efficiency for each component):

$$\eta_{BATTERY-SUPPLY} = 88\% * 99\% = 87.12\%, \text{ and} \tag{8}$$

c) charging efficiency of the battery when charged from the photovoltaic display and the power grid, respectively (the minimum efficiency of each component):

$$\eta_{BATTERY-CHARGE(PV)} = 95\% * 80\% * 99\% = 75.24\%, \tag{9}$$

$$\eta_{BATTERY-CHARGE(PV)} = 88\% * 95\% * 80\% * 99\% = 66.21\%. \tag{10}$$

2.7 System power generation

An MPPT control mode was adopted according to a 20 KW, 110 V photovoltaic battery system with a battery charge current for 2A all-weather float design system. The photovoltaic power generation system is:

$$E_{system} = E_{PV} * \eta_{MPPT} * \eta_{MM} * \eta_{L} - (I_f * V_f * T_{CH}) = 20000 * 95\% * 95\% * 98\% - (2 * 120 * 24) = 11.929 \text{ KW} \tag{11}$$

The developed storage system can also transmit an average power of 11.929 KW to the power grid.

3. Model Simulation and Results

3.1 System simulation model

To validate the proposed reserve power supply system, the MATLAB/Simulink environment was used to simulate the design that included a photovoltaic cell model, DC/DC converter, DC/AC converter, lead-acid battery and load model, as shown in Fig. 2. Here the photovoltaic cell model had the following inputs illumination (*S*) and temperature (*T*); the negative and positive output poles were represented by output− and output+, respectively. The DC–DC converter was represented by a boost-type boost converter and an MPPT control module was used, which contained 2 inputs (current *I* and voltage V) and 2 outputs (the IGBT drive signal *G* and output power *P*). The output *P* can be used to test the output power of the photovoltaic. The figure in the right side is the gray control module, and the upper module is the driving signal G through the MPPT algorithm, while the lower power calculation has the input voltage and the input current product. The later stage of photovoltaic power generation system will convert the DC power from the PV cell to AC power using the inverter before connecting to the grid. The inverter was modeled as a three-phase, two-level voltage source converter with three bridge arms each containing two IGBT.

An inductor filter was used to filter the power grid's current. The output port of the inverter is followed by load and power grid and contained two switches, a power switch (upper red switch) and a load switch (lower red switch). When the external control signal of the switch is 1, the switch is closed. When the signal is 0, the switch is disconnected. The power grid was simulated with a three-phase power supply and the load was simulated with a three-phase active load. The gray module under the inverter is the control module of the inverter.

The system can be run on- or off- network under PQ or VF control. The input signal of the three-phase current *I*, the three-phase voltage *U*, and the algorithm switching control signal are controlled. Control signals of 0 or 1 indicate on- or off-grid operation. The Dq transform module was used to to convert the three-phase signal to a two-phase signal. Because of the need for the positive cosine signal, the positive cosine signal can be obtained by the phase-locked loop. A PI regulator was used to track the reference value of the current for internal current control. The modulation strategy uses a sinusoidal pulse width modulation strategy. The output signal can select 6 path pulses according to the topology.

Battery capacity, voltage, and initial SOC parameters were set to test the voltage, current, and SOC of the battery. The SOC and power of the battery were obtained by testing. A positive or negative battery power indicated that the battery was discharging or discharging. A 500 Ah battery with an initial SOC of 80% were used for the purposes of this study.

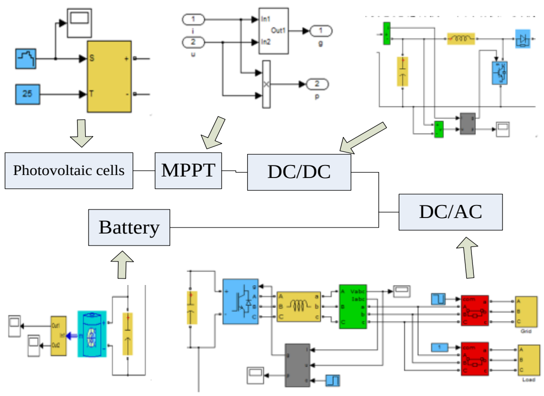

Fig. 2. Diagram of system topology

3.2 System simulation

Simulations were then performed under the following conditions:

a) a maximum output power of the 20 kW photovoltaic of 0.2 S, and the intensity of the 0.7s is 0,

b) an inverter output power of 15 kW with a load power of 10 kW,

c) a battery capacity of 500 AH with an initial SOC state of 80%, and

d) a power network blackout occurring at 0.3s and an automatic switch off of the power grid at 0.6s.

Initial simulation results of the resulting output power trends are shown in Fig. 3 and Fig. 4. The output power of the photovoltaic cells changed with changing of light intensity, and at night when 0.7S is in the state. At that time, the battery via the power grid, as no sunlight is available.

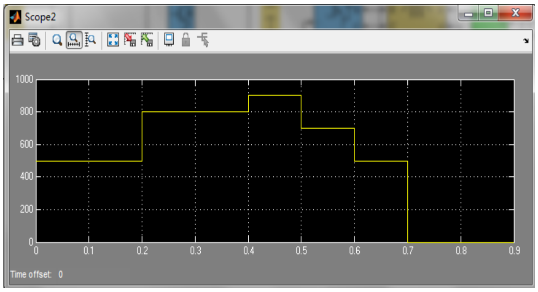

Fig. 3. Variation curve of light intensity

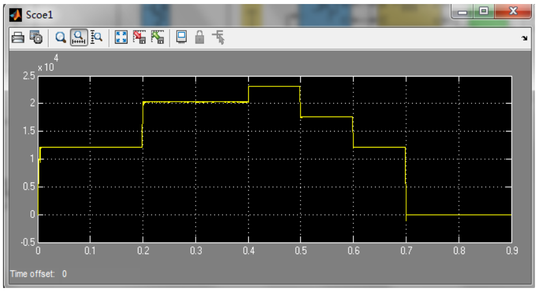

Fig. 4. Simulation results of PV power output

A more-thorough simulation was then performed; results are shown in Fig. 5 –Fig. 10. The system was able to achieve maximum power tracking using the MPPT algorithm as the solar irradiation varied.

a) The output power of the high intensity of light is greater than the output power of the inverter 15kW. In the process of grid connection, the excess power will charge the battery.

b) When the light intensity is small, the output power of the photovoltaic is less than the output power of 15kW. The insufficient part of the power required for the load will be supplied by the battery. At this time the battery works in the discharge state, so the battery charge and discharge range can be adjusted by controlling the power of the inverter in real time.

c) When the power network of 0.3s is simulated, the power drop of the power grid is zero, as shown in Fig. 7. At this time the inverter works in the mode of off network, power supply to the 10kW load. As shown in Fig. 5, the output power of the inverter is 10kW, equal to the load power.

d) At 0.6s, the closed grid switch is closed. At this time the inverter works in the grid mode. As shown in Fig. 6, the output power of the inverter is tracked on the power instruction. The output power is 15kW, because the load is 10kW, so the power of the power grid is 5kW.

e) At night, as shown in Fig. 3, the intensity of the illumination at 0.7s is 0. At this point the output power of the PV unit is 0. At this time the battery carries on the load to carry on the discharge, guarantees the load uninterrupted power supply demand. As you can see from Fig. 10, the power of the battery is 15kW.

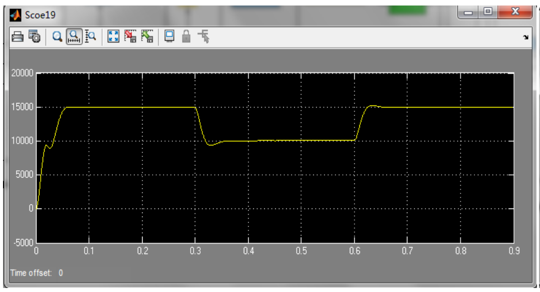

Fig. 5. Simulation results of inverter output power

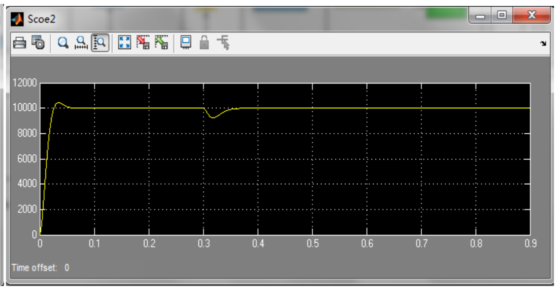

Fig. 6. Simulation results of load power

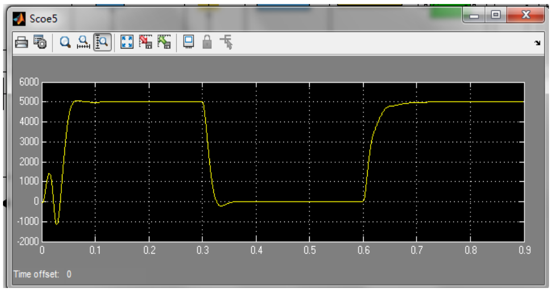

Fig. 7. Simulation results of power

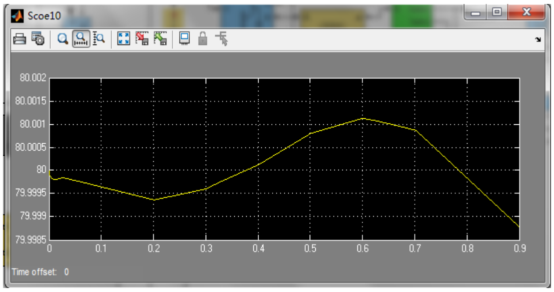

Fig.8. Simulation results of Battery SOC

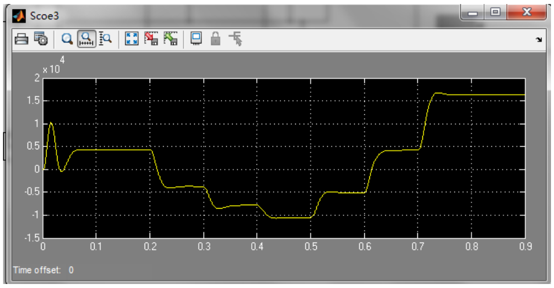

Fig. 9. Simulation results of battery output power

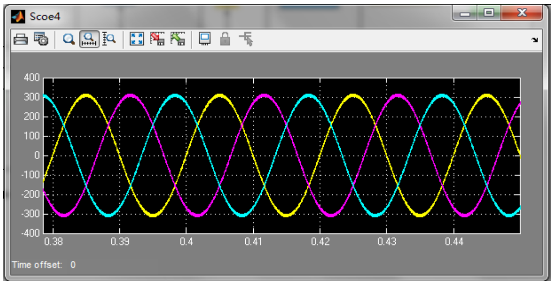

Fig. 10. Simulation results of load terminal voltage in fault

4. Conclusion

A novel backup power system based on PV panels and a lead-carbon battery was proposed to increase a substation's reliability. During daylight hours, the PV panel system is used to charge a lead-carbon battery to provide a more stable backup power system, while the power command adjustment of inverter ise used to realize battery charging or discharging, realizing and switching off the network. The battery can supply power by discharge to the load even if there is an electric power failure in the case of insufficient lighting at night. To ensure the uninterrupted power supply operation of important load, it is of great significance for the reliability of power supply system for substation station.

Acknowledgments

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