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Performance Analysis of PV Energy System for Pulse Loads

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Abstract. At present, there are more and more pulse loads in military weapons. The specific performance is periodic sudden increase and anticlimax in power. The capacity of photovoltaic power generation with external battery is unable to respond to frequent mutations in the load quickly, due to its limited capacity and slower charge-discharge rate of battery. This paper build the simulation model about the photovoltaic energy system for Power Supply to Weapon Equipments and study the effect law of pulse load on the photovoltaic energy system. Through the method for calculating operation parameters of microgrid, the influence of pulse load with different parameters was carried on the selective analysis. The operation of pulse load results in the fluctuation of bus voltage and the decrease of power transmission efficiency. The influence of pulse load with the different parameters on the system is not the same.

1. Introduction

In order to get rid of the dependence on diesel generators in military power supply, photovoltaic devices equipped with energy storage are increasingly used for power supply in front-line bases due to their characteristics of no fuel consumption, good mute, simple maintenance, high efficiency and cleanliness [1]. However, with the progress of science and technology, a series of pulse loads with larger peak power have appeared in the power load of our weapons and equipments, such as phased array radar, electromagnetic rail weapon and so on. The impact load not only has an impact on the power supply when starting and stopping, but also causes repeated load and unload on the power supply during normal operation, thus affecting the output characteristics of the PV energy system.

The pulse load has a small average power, high peak power and a typical pulse characteristic. Usually, the operating cycle of the pulse load is approximately ten to hundreds of milliseconds. For the common pulse load structure, the transient power characteristics of the pulse load with different parameters are analyzed in the public power grid and off grid respectively in literature [2]. Literature [3] analyzed the impact of pulse power load on the DC side voltage of a diesel-generator-rectifier system. The experiment results show that increasing the filter capacitor can properly improve the DC voltage. The high energy pulse load model is established in literature [4]. And the impact of the high-energy pulse load directly connected to the integrated power system is verified by simulation. But the above literatures are all about the impulse load in the power supply system, which is the main body of the diesel engine. The operation characteristics of the military load under the PV energy supply system are not analyzed and discussed in detail.



In this paper, the operating characteristics of the PV energy system in the equipment supply are taken as the research object. According to the characteristics of the system operation, a simulation model is constructed and simulated separately for pulse loads. The influence of pulse load on the power quality and power transmission efficiency of the PV energy system is emphatically studied.

2. Structure and working principle of PV energy system

2.1. Simulation Structure of Photovoltaic Cell

According to the I-V relationship of photovoltaic cells, a PV cell model is built and a correction compensation coefficient is introduced to obtain the correction value of the PV cell electrical parameters in any case. Then the conductance incremental method is used in the boost circuit to achieve the maximum power point PV cell control, as shown in Fig.1. Through the P-U curve of the photovoltaic array, the slope of the maximum power point is zero, as shown in equation (1).

$$\frac{dP_{PV}}{dU_{PV}} = \frac{d(U_{PV}I_{PV})}{dU_{PV}} = I_{PV} + U_{PV} \frac{dI_{PV}}{dU_{PV}} = 0 \quad (1)$$

Simplify the equation (1) and get the equation (2).

$$dP_{PV}/dU_{PV} = -I_{PV}/U_{PV} \quad (2)$$

The transient conductance is equal to negative number of its change rate. According to equation (2), the S function is written to change the duty cycle of the PWM wave, so that the photovoltaic cells work at the maximum power point voltage.

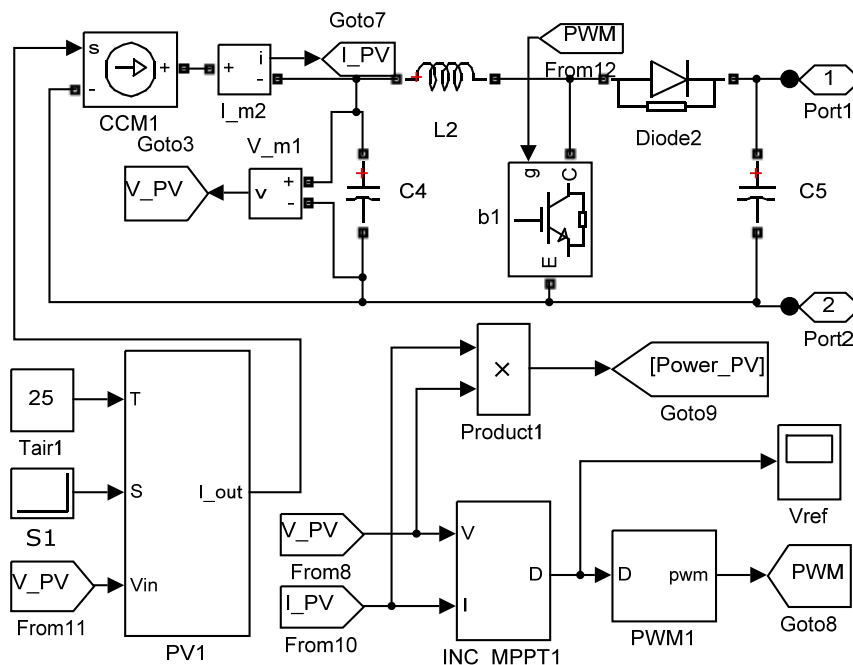


Figure 1. Photovoltaic cells and MPPT control simulation structure

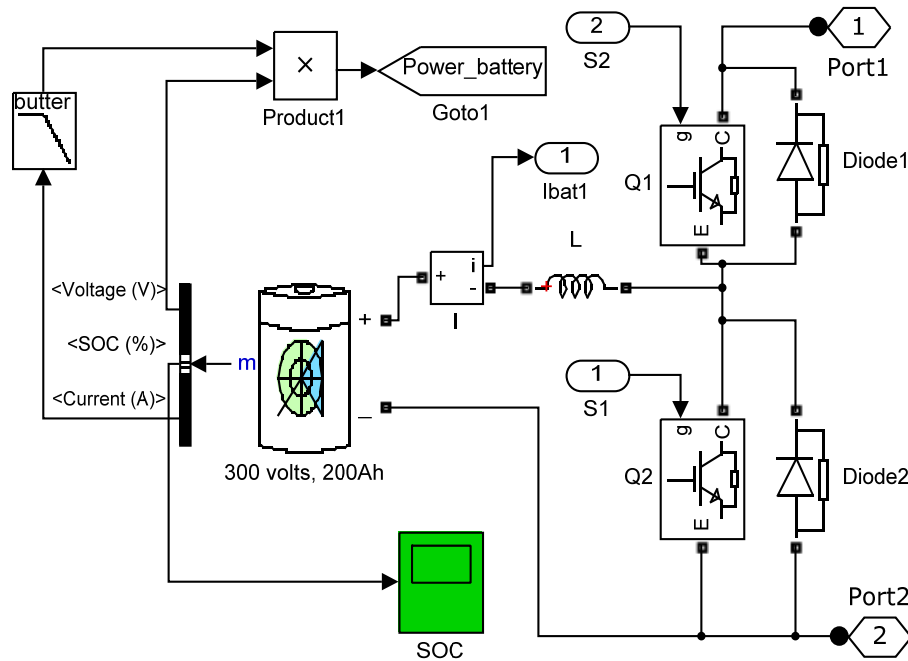


Figure 2. Simulation structure diagram of energy storage device

2.2. Simulation Structure of Energy Storage Device

The simulation structure of energy storage device is mainly composed of battery, buck-boost circuit and PI control unit. The model is shown in Fig.2. The basic design idea is: first, the current regulator in the current loop is designed, then the current loop is simplified into a link in the voltage loop, and other links are used to form the control object of the outer loop voltage regulator. The output of the voltage loop is given as a current loop, and the current is controlled by voltage. The battery current and the DC bus voltage are taken as the sampling signals of the current inner loop and the voltage outer loop respectively. The PID module in Simulink is used as the PI regulator. Finally, the PWM generator module outputs PWM wave to realize the double closed-loop control. The control unit model is shown in Fig.3.

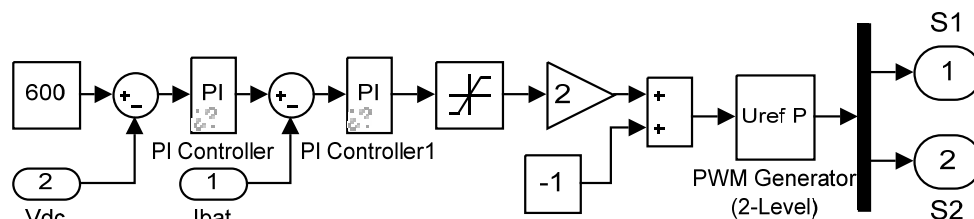


Figure 3. Control unit model

3. Simulation Test of PV Energy System

The simulation parameters of PV energy system are as follow: under the standard conditions ($T = 25^\circ\text{C}$, $S = 1000\text{W/m}^2$) the short-circuit current I_{sc} is 18.3A, the open circuit voltage U_{oc} is 350V, the maximum power point voltage U_m is 300V and the maximum power point current I_m is 14.5A of the photovoltaic cell. The nominal voltage of the battery is 300V, and the capacity is 200Ah. The temperature T is kept at 25°C , and the initial irradiation value is 800W/m^2 .

The common pulse load weapons include phased array radar, electromagnetic rail weapon, and laser weapon and so on. According to their load characteristics, a simulation model is built to simulate the pulse load. The simulation model is shown in Fig.4.

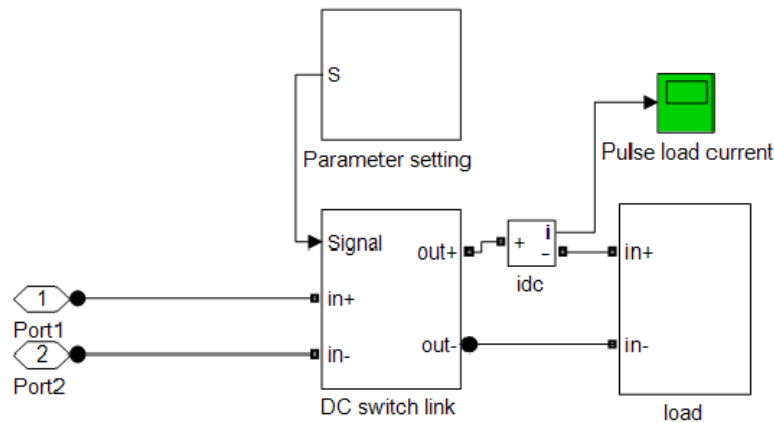


Figure 4. Pulse load simulation structure diagram

The pulse load simulation structure mainly consists of DC switch, parameter setting link and load. By setting the working cycle T_s , the duty cycle D and the peak power P_L , the model can obtain the different performance characteristics of the pulse load under different parameters. The duty cycle can be adjusted by adjusting the ratio of switch closing time to the whole switching period. The periodic interruption of pulse load can be simulated by adjusting the switch period. The peak power is adjusted by adjusting the pulse load resistance. The DC bus voltage line of the PV energy system is 600V. The peak power of P_L is 10kW, the duty cycle D is 0.4, and the working period T_s is 56ms. The simulation time is 1s. The power of the PV energy system and the bus voltage are shown in Fig. 5 (a) and (b).

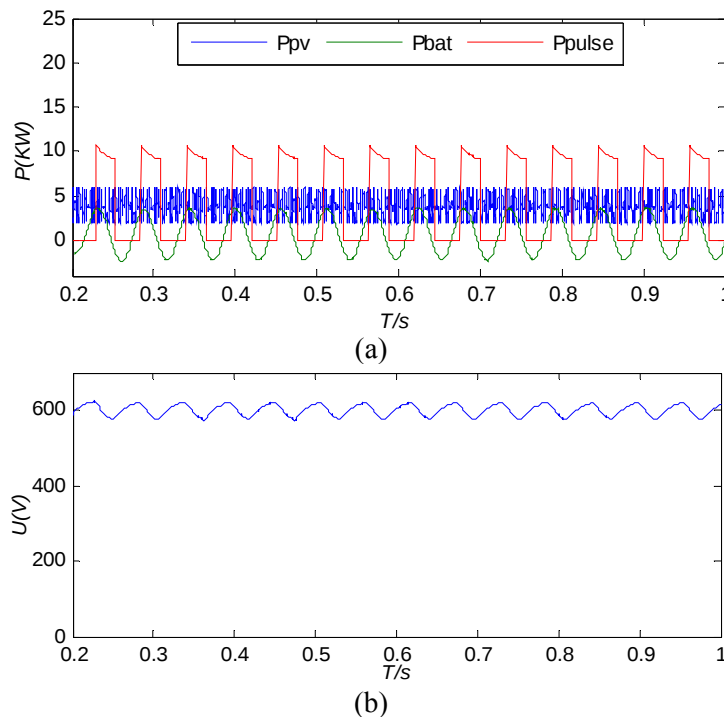


Figure 5. (a)Output power waveform of each part of photovoltaic energy system under pulsed load. (b) DC bus voltage waveform under pulse load.

Fig.5 (a) reflected the curve of the output power of the PV energy system during the simulation. During the peak load of the pulse load, the sudden increase in load causes the PV array power to be less than the load power due to the constant PV output. The power density of battery is too low and the power changes fast, which causes the system cannot effectively respond to power mutation caused by pulse load.

As can be seen from Fig.5 (b), with the periodic sudden change of pulse load current, the output voltage also fluctuates periodically, and the amplitude of the fluctuation is large. Because the system does not consider the output power fluctuation of the photovoltaic, the load fluctuation is the main reason for the voltage fluctuation of the DC line. The switching of pulse load leads to the imbalance of active power, the sudden increase of power leads to the rapid decline of DC bus voltage. In the pulse gap, the voltage rises slowly under the action of double closed loop regulator, but the overshoot is too large which makes the setting time longer than the duty cycle of the pulse load. Thus, the voltage is always in a fluctuating state and cannot return to the 600V setting value.

In order to understand the effect of pulse load on power quality and transmission efficiency of PV energy system more intuitively, the microgrid operation parameters under different pulse loads: the voltage average U_{dc} , DC voltage fluctuation δu , pulse load power P_{dc} , average battery P_b (When P_b is positive, the battery is charged. When P_b is negative, the battery is discharged.), power transmission efficiency η are calculated, as shown in Table 1.

The pulse load shows a normal load characteristic when $D=1$. And the power transmission efficiency is the highest and the voltage fluctuation is the smallest. It can be seen from the comparison that the pulse load will cause large voltage fluctuation and power loss of the PV energy system. The pulse loads with different parameters affect the system differently. Pulse duty cycle and working cycle have significant effects on voltage fluctuation. When $D = 0.5$, the voltage fluctuation is the most serious. When the duty cycle is constant, the voltage fluctuation increases with the increase of T_s . The power transmission efficiency decreases at first and then increases with the increase of duty cycle. The efficiency is the lowest when $D=0.5$. The change of T_s has almost no effect on transmission efficiency.

Table 1. Dynamic characteristics of the system under pulse loads with different parameters

D	T_s	U_{dc}/V	$\delta u/\%$	P_b/kW	P_{dc}/kW	$\eta/\%$
0.1	56	598.8	2.06	-2.41	0.95	88.2
0.3	56	598.1	5.34	-0.52	2.69	76.1
0.5	56	601.3	6.25	1.75	4.51	81.3
0.7	56	604.5	5.29	3.61	6.74	87.9
1	56	600.1	0.53	6.60	9.62	92.5
0.4	20	600.2	2.16	0.71	3.81	84.5
0.4	40	599.2	4.25	0.69	3.78	84.9
0.4	70	596.8	7.26	0.69	3.80	84.6
0.4	90	601.1	8.80	0.72	3.83	85.7

4. Conclusion

In this paper, the PV energy system power supply model is established by Matlab / Simulink software. The operation characteristics of the PV energy power supply system under impact and pulse load are studied, and the specific influence of pulse load on the power quality and power transmission efficiency of the PV energy system is qualitatively analyzed by calculating the operation parameters of the microgrid under different parameters of pulse load. When the pulse load is connected, the system bus will have a large voltage fluctuation, and the power transmission efficiency is reduced. The simulation results will be applied to the research on improving the quality of the power supply of weapons and equipment.

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