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Performance comparison of series and parallel DC power supply system

Shengli Kong ^{1,a}, Xudong Leng ², Weidong Ma¹, Lei Liu ¹ and Feng Zhang³

¹State Grid Henan Electric Power Research Institute, China

²Shenzhen Tieon Energy Technology Co.,Ltd., China

³Henan EPRI Hitech Group Co.,Ltd., China

kongshengli@139.com

Abstract. Since the structure of series DC power supply system, if any battery cell breaks down, the group of battery cells can't play its due role. The parallel DC power supply system has been successfully developed and applied in recent years. We want to know whether the parallel DC power system is worth vigorously popularizing and applying in the substation in the future? So we made a few special tests, and this paper will compare the series and parallel DC power supply systems with some data in some ways, such as performance, safety, reliability, maintenance quantity, convenience, economic benefits , etc.

1. Introduction

The traditional DC power supply system used in substation is composed of charger and series-connected batteries. The parallel DC power system developed in recent years consists of several parallel battery components. Because the batteries of the former are connected in series, the DC power supply system is greatly affected by such a structure. If the circuit is open, or single battery breaks down, or old and new batteries are mixed, the group of battery cells won't play its due role [1]. The battery of the latter is a parallel structure, so the latter is called "parallel DC power system". Therefore in this paper, we call the traditional DC power system "series DC power system".

At present, series DC power supply system is widely used in substation and has been running for decades. Parallel DC power supply system is an emerging product, which has obvious advantages on structure, but we want to know whether it also has advantages over performance, safety and other aspects. This paper intends to carry out detailed comparison of series and parallel DC power system through tests as comprehensive as possible.

2. Parallel DC power system technology

2.1. Parallel battery component

In order to solve the problem caused by the structure of series DC power system, "parallel battery component" was innovatively designed by combining one 12V battery with matching AC/DC and DC/DC charge-discharge circuits [2]. The module designed with AC/DC and DC/DC circuits is called "parallel battery module" [3].



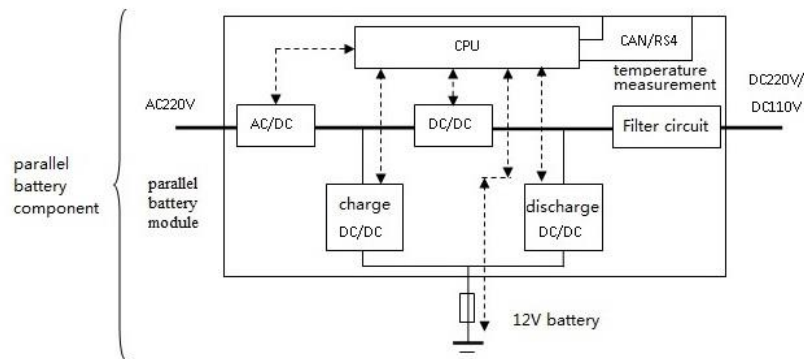


Figure 1. Schematic diagram of parallel battery component.

2.2. Technical performance and parameters of parallel battery modules

2.2.1. Input characteristic.

Table 1. Input characteristic.

	Min. value	Rated value	Max. value	Remarks
AC input voltage	95Vac	220Vac	285Vac	Normally starting and running at entire voltage range
AC input frequency	45Hz	50Hz	65Hz	Normally running at entire frequency range
AC input current			8.5A	Input:90~108Vac; Output:440W
AC starting impulse current			30A	Input:265Vac; 25 °C; Duration>1mS
Battery input voltage	10.8Vdc	13.4Vdc	14.1Vdc	Normally starting and running at entire voltage range

2.2.2. Output characteristic.

Table 2. Output characteristic.

	Value	Remarks
Main rated output voltage	220/110Vdc	
Main rated output current	2/4A	
Rated power of output	440W	
Efficiency	≥87%	AC power supply; Main output: 2A; Charging output: 20A, environment ; 25° C
Efficiency	≥90%	Battery discharge; Nominal voltage input; Rated output voltage current; 25° C
Module softly starting time	3~8S	Resistance load; AC power supply
Current stability accuracy (charging output)	≤±1%	Test method following GB/T 19826-2014 6.3.2
Voltage stability accuracy (charging output)	≤±0.5%	Test method following GB/T 19826-2014 6.3.3
Voltage stability accuracy (main output)	≤±0.5%	Test method following GB/T 19826-2014 6.3.3
Ripple factor (charging output)	≤0.5%	Test method following GB/T 19826-2014 6.3.4
Ripple factor (main output)	≤0.5%	Test method following GB/T 19826-2014 6.3.4
Flow unbalance of parallel module	≤±5%	Test method following GB/T 19826-2014 6.7

2.3. Parallel DC power supply system

The parallel DC power supply system is made up of several parallel battery components, and the corresponding monitoring equipment and feeders [4-5].

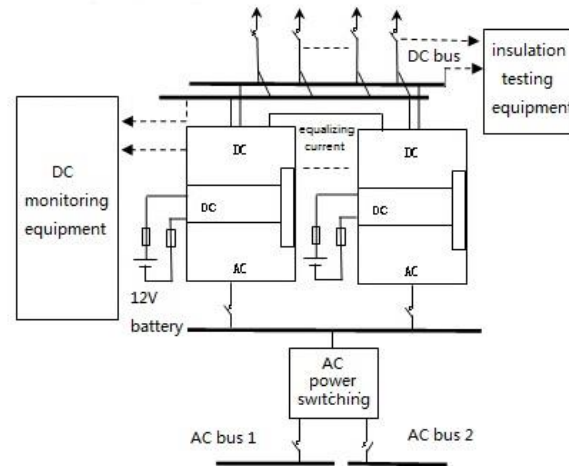


Figure 2. The structure of single - bar parallel DC power supply system.

3. Performance comparison of series and parallel DC power supply system

3.1. Comparison of system structure

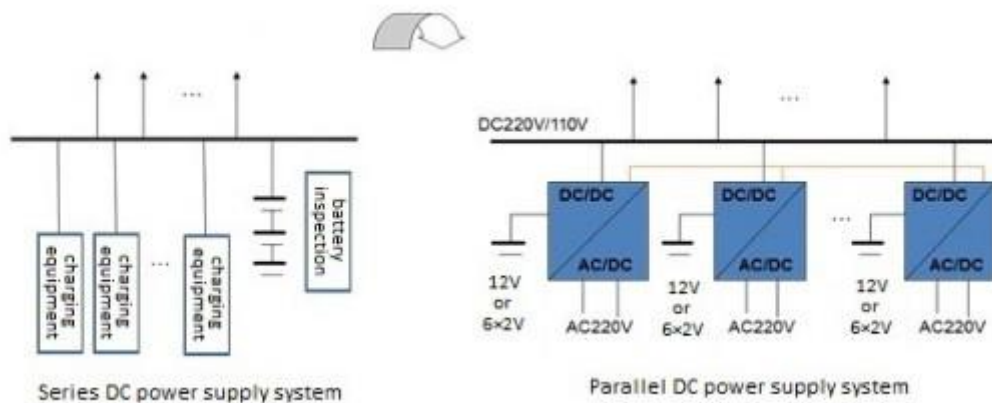


Figure 3. The structure comparison of two different principle system.

3.2. Performance comparison

Table 3. Performance comparison.

	Parallel DC power supply system	Series DC power supply system
Voltage stability accuracy	$\leq \pm 0.5\%$	$\leq \pm 0.5\%$
Current stability accuracy	$\leq \pm 1\%$	$\leq \pm 1\%$
Efficiency	Rectifier efficiency $\geq 90\%$; Battery discharging efficiency $\geq 95\%$	Rectifier efficiency $\geq 90\%$; Battery directly discharging without loss
Noise level (dB)	Self-cooling < 45	Air cooling < 55 ; Self-cooling < 45
Charge and discharge	One-to-one management	One-to-many management

management**Battery connection mode**

Indirectly parallel(can be mixed with old and new)

In series(High consistency requirement) [6]

*3.3. Safety comparison***Table 4.** Safety comparison.

	Parallel DC power supply system	Series DC power supply system
Anti-explosion	Anti-explosion and flame-proof treatment for 12V cell	Special battery room for series-connected batteries with capacity $\geq 300\text{AH}$

*3.4. Reliability comparison***Table 5.** Reliability comparison.

	Parallel DC power supply system	Series DC power supply system
Effects of the breakdown of cell battery	Will have no effects on the system [7]	Will affect the output of whole battery group
Effects of the breakdown of several cell batteries	Batteries with fault can be replaced independently without affecting the system reliability	Several batteries with fault will cause the whole battery group to be scrapped

In reliability mathematics, the reliability rate of the system is expressed as K , and the failure rate is expressed as G , so $K+G=1$. DC power supply system in series would reduce the reliability of the system. If the two same reliability rates are K_1 and K_2 , the reliability rate K of series DC power supply system is K_1K_2 , and the failure rate G is $1-K_1K_2$. Two parallel systems of the same function are called redundant systems, which can improve the system reliability. If the two same reliability rates are K_1 and K_2 , and the failure rates G_1 is $1-K_1$ and G_2 is $1-K_2$ [8].

On the basis of experience, we can assume that the reliability rate of a 2V VRLA(Valve Regulated Lead Battery) is 99.95%, the reliability rate of a 12V VRLA is 99.9%, and the reliability rate of a parallel battery module is 96%. Since a parallel battery component is connected with a parallel battery module and a 12V VRLA in series, its reliability rate is $96\% \times 99.9\% = 95.9\%$.

The theoretical reliability calculation of the two DC power supply systems belonged to 110kV substations is stated as follows (according to the reliability formula of series and parallel system):

● Series: For 108 VRLA (2V, 200AH) in series, the reliability rate of the battery group is $(99.95\%)^{108} = 94.7\%$, and the failure rate is 5.3%. The reliability rate of two series DC power supply systems is $1-(5.3\%)^2 = 99.72\%$.

● Parallel: According to the bidding technical data of a 110kV substation in Guizhou, there are 5 10A /220V charging modules in the original series DC power supply system. If we remove the stand-by module and the battery charging current (20A), we can get that the actual fault current is 20A. The parallel DC power supply system is equipped with 24 parallel battery components, each of which is rated at DC220V/2A. We can calculate that there are 14 stand-by components. While considering discharge capacity, there are actually 3 stand-by components. Since the failure rate of each component is $(1-95.9\%) = 4.1\%$, the reliability rate of the parallel DC power supply system is $1-(4.1\%)^3 = 99.99\%$.

*3.5. Convenience comparison***Table 6.** Convenience comparison.

	Parallel DC power supply system	Series DC power supply system
Installation	High(No battery inspection device; 12V battery; the number of cell battery is reduced)	Middle
running	High(Can check 100% capacity online with	Low

	0.1C discharging current)	
Maintenance	High(Can replace cell battery online)	Middle
Technical improvement	High(Old and new battery can be used in the same system)	Middle

3.6. Maintenance workload comparison

Table 7. Maintenance workload comparison.

	Parallel DC power supply system	Series DC power supply system
Workload of checking capacity and cost	Low(Can check 100% capacity online with 0.1C discharging current; 12V battery; the number of cell battery is reduced)	High(Can check capacity offline; external backup battery group will be needed; heavy workload)
Repairing workload and cost	Low(Can repair every cell battery)	High(Several batteries with fault will cause the whole battery group to be scrapped)

4. Economic comparison of series and parallel DC power supply system

4.1. Configuration comparison

Suppose there is a 110kV substation with series DC power supply system which is composed with double chargers and double battery groups. This paper is going to compare such a series DC power supply system with parallel DC power supply system.

Table 8. Comparison table of main components.

	Parallel type	Series type
AC switching circuit	1 set	2 sets
Charging module	24 parallel battery module. Parallel battery module isn't just a rectifier, but also a management of battery charging and discharging.	2 sets of 5 charging modules (DC220V/10A)
Battery	24 lithium iron phosphate batteries (12V/200Ah). The cell batteries are independent and have no direct electrical connection.	2 sets of 108 VRLA (2V/200Ah). The cell batteries are connected in series.
Battery inspection equipment	No. Parallel battery module is a one-to-one battery management.	2 sets
Stepdown silicon chain	No. DC bus-bar voltage is stable since the battery is not connected to the DC bus-bar.	2 sets. DC bus-bar voltage is sometimes a little high while charging the battery group on the bus-bar.
DC monitoring equipment	1 DC monitoring equipment +1 parallel battery module.The monitoring equipment of parallel battery module mainly controls checking battery capacity.	2 sets
External backup battery group	No. Parallel DC power supply system can check 100% capacity online.	1 set
Insulation testing equipment	2 sets	2 sets
DC feeder switch	As needed	As needed

4.2. Full life cycle (12 years) benefit comparison

●Cost of equipment purchase: The purchase cost of Parallel DC power supply system and series DC power supply system is similar.

● **Cost of checking battery capacity:** For such a series DC power supply system, there will be 10 times to check the battery capacity. If once it will cost \$8,000, the total cost of checking battery capacity is \$80,000. While parallel DC power supply system can check battery capacity online, this cost will be saved.

● **Cost of replacing battery:**

For such a series DC power supply system, we have to shut off the electric power supply to replace the battery group. On the basis of replacing one set every 6 years, one new set should be purchased in the 7th year which costs \$120,000. As so on, another new set should be purchased in the 12th year which also costs \$120,000. The remaining 90% value of the batteries is about \$108,000, so the actual cost of replacing the battery during the 12-year life cycle is \$132,000.

For parallel DC power supply system, in the first six years, 20% of the batteries have to be replaced which costs \$28,000. The rest of the batteries should be replaced in the 10th year which costs \$112,000. The remaining 30% value of the batteries 6 years before and the remaining 90% value of the batteries 2 years before are \$109,200. So the cost of replacing the battery during the 12-year life cycle is \$30,800.

Through the above comparison we can know that parallel DC power supply system costs 30% less than Series DC power supply system during the 12-year life cycle.

5. Comparison of overload capacity based on improvement

5.1. Overload output characteristic curve of parallel battery module

Overload output characteristic curve of parallel battery module is shown in Figure 4.

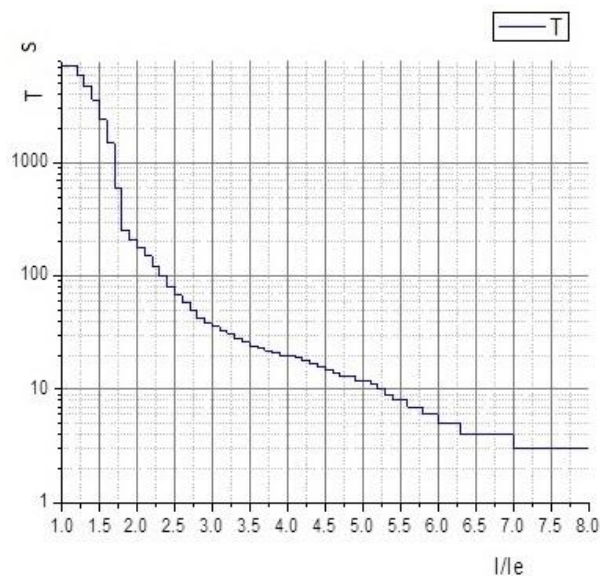


Figure 4. Overload output characteristic curve of parallel battery module.

5.2. Continuous current circuit of series battery based on parallel DC Power Supply System

On account of every battery branch independent from with AC bus-bar, DC bus-bar, and other battery branch, we connect 16 or 8 2V cell batteries to the DC bus-bar with discharge diodes and fuses, whose voltage is lower than the voltage of DC bus-bar. The batteries in series only have the discharge path to the DC bus-bar. The schematic diagram of continuous current circuit of series battery based on parallel DC Power Supply System is shown as Figure 5.

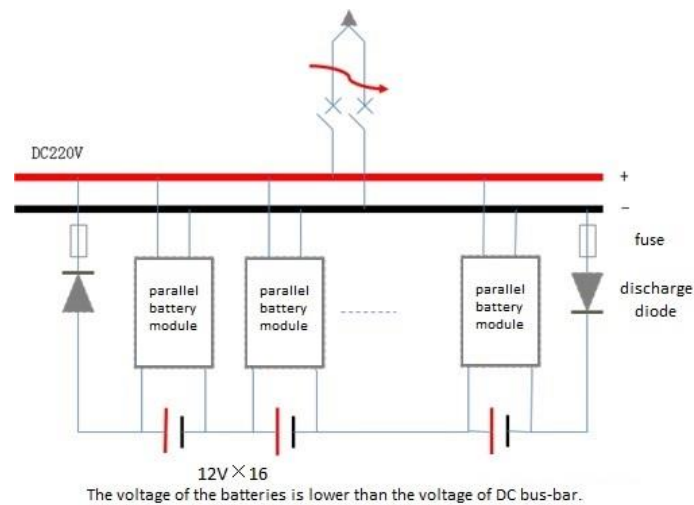


Figure 5. The schematic diagram of continuous current circuit of series battery based on parallel DC Power Supply System.

Normally, it is carried by the parallel battery module with stable voltage. When the system is overloaded or short-circuit fault occurs, the current is still provided by the parallel battery module. If the DC bus-bar voltage is pulled down to the series battery voltage, the batteries in series will provide continuous current at the same time [9-10].

The short circuit test waveform of feeder lines for 16 batteries in series is shown as Figure 6. If 16 12V batteries in series and 16 parallel battery modules run simultaneously, the short circuit test waveform of feeder lines is shown as Figure 7.



Figure 6. Short circuit test waveform of feeder lines for 16 batteries in series (1mV is corresponding 4A).



Figure 7. Short circuit test waveform of feeder lines for 16 12V batteries in series and 16 parallel battery modules running simultaneously (1mV is corresponding 4A).

The test results show that the overload effect of the parallel DC power supply system is higher than that of the traditional series DC power supply system. When the short-circuit fault of feeder occurs, the bus-bar voltage will drop less, and the bus-bar voltage recovery time is shorter after fault removal.

6. Conclusion

The parallel DC power supply system has been applied in 110kV substation, 35kV substation, 20kV switching station and 10kV switching station since 2012. The advantages of the parallel DC power supply system are obvious: (1) It solves the problem of single cell battery's fault affecting the output of whole battery; (2) It solves the problem of several batteries with fault causing the whole battery group to be scrapped; (3) Mixing old and new battery in one system is allowed, and it improves battery utilization; (4) It makes check 100% capacity online and repair every cell battery come true; (5) The application is flexible, which can be centralized and distributed, and promote the integration development of primary and secondary equipments of substation. On the other hand, at present, the power of parallel battery modules is relatively small, which is limited in high-power applications.

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