EPH - International Journal of Applied Science

ISSN (Online): 2208-2182
Volume 05 Issue 01-March-2019

DOI: https://doi.org/10.53555/eijas.v5i1.39

RESEARCH ON HIGH RELIABILITY AREA POWER DISTRIBUTION TECHNOLOGY FOR SHIPS

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Abstract:-

The research of power supply reliability is the basis of the application of power system on large warships. With the improvement of the demand for the vitality of warships and the need for the research of all-electric propulsion ships, the annular regional distribution network will be paid attention to and become the direction of the future development of warship distribution. In the whole research process, this paper strives to make the theoretical demonstration rigorous, proceeding from reality, and make it have greater practical value as far as possible.

Keywords:-*Ship power system, Reliability, Circumferential area distribution*

INTRODUCTION

With the development of science and technology, electric propulsion mode and the emergence of a variety of high-performance weapon, as well as the integrated power system concept [1, 2], the ship power system capacity increasing, and the electricity equipment is becoming more and more high to the requirement of power supply reliability[3-5], power system network topology is also increasingly complicated, at the same time, the analysis and calculation of short-circuit fault system becomes more difficult[5, 7].

Statistical data show that 80% of power failures are caused by distribution network faults, and the reliability of distribution network is getting more and more attention. Improving the reliability of distribution network plays an important role in improving the power supply quality of power system [8]. The design of ship power grid is directly related to the reliability of power supply, so the importance of power grid is no less than that of power station [9, 10]. No matter how good the performance of a power station is, it cannot function without a good grid. Practice shows that choosing the appropriate power supply mode and distributing mode not only can save a lot of cable[10-13], improve efficiency, but also for power grid comprehensive monitoring provides great convenience, more easy to realize automatic control, improve the level of automation, fault easier and faster after the implementation of the network reconfiguration, can effectively improve the life and reliability of ship, the ship especially combat ships has the vital significance [14].

1. Common grid forms of ships

There are five basic types of ship power network: main, feeder, hybrid, ring and network.

1. In the mainline type, several mainline cables are drawn from the main switchboard, and all electrical equipment is powered by a branch junction box connected to the mainline in series, as shown in figure 1. This kind of distribution is simple in structure, less in number and lower in cost. Suitable for submarine electrical systems that wish to minimize the number of cables passing through the watertight cabins. The disadvantage is that when the fault occurs in the main feeder cable, all the power supply equipment in this main line will be cut off, so the reliability of power supply is not high and the application is less.

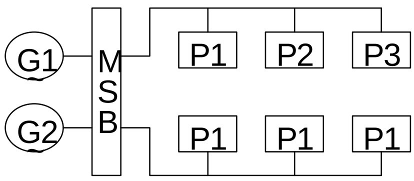


Fig.1 Main route distribution network

2. Feeder type (also known as radial type) each cable is directly drawn from the main switchboard and only supplies power to one electrical equipment or one distribution board respectively, as shown in figure 2. The advantage is to facilitate centralized control, a branch feeder line failure only affects the supply of this branch power supply of an electrical equipment or the distribution box. However, the use of too many cables, any one line of load failure will have a great impact on the main switchboard, which reduces the actual reliability of the system, suitable for less power equipment and the reliability requirements of ships.

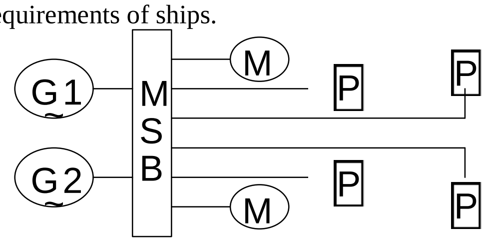


Fig.2 Radial distribution network

3. Hybrid distribution has the characteristics of both trunk and feeder type, that is, one part of the distribution box or load adopts feeder distribution mode, and the other part adopts trunk distribution mode, as shown in figure 3. Usually the former belongs to the load with more power or more important, while the latter is the load with less power or less important. Its advantage is that local line fault will not affect the whole power system, if the reasonable configuration, high reliability, the most widely used.

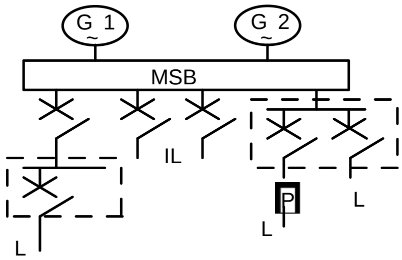


Fig.3 Hybrid distribution network

4. Ring distribution mode. Each section of the bus is connected with the load distribution board in series by the busbar linkage switch to form a closed ring network, as shown in figure 4. The four generator switchboards are connected in a ring by cables and circuit breakers.

Loop network can form more power station to load path, each load can get power from two directions of the line, so the fault of either line will not make the line stop power supply, so as to better meet the reliability requirements of power supply. According to the connection wire, the ring system can be divided into full closed loop, power loop and load loop. Figure 4 shows the form of a power loop.

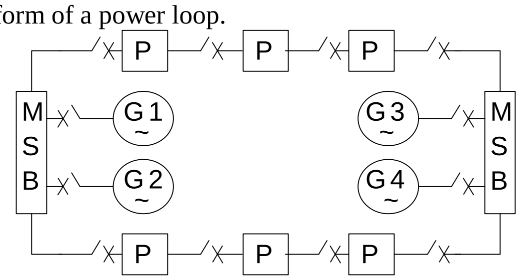


Fig.4 Loop distribution network

As can be seen from the form of ring distribution, a highly reliable power supply can be expected as long as there is appropriate margin and proper operation, but a series of problems must be solved, such as line protection, system monitoring, and adjustment and so on. In recent years, due to the application of electronic computers in power system monitoring and control technology and the progress of power system stability research, the ring network system has been considered as a promising power distribution method for the future development of ship power grid.

2. Regional distribution structure

2.1 Regional distribution overview

The continuity of power supply is an important index to measure the vitality of power system. Especially when the power system is damaged due to failure or battle, whether the continuity of power supply can be maintained to the maximum extent is the first problem that needs to be solved. Although the important loads usually have redundant power supply to ensure continuous power supply, too much redundant power supply equipment and lines will increase the complexity of the system, thus reducing the reliability of the system, and also increase the construction cost of ships, daily maintenance workload and maintenance costs, which are not conducive to the development of modern ships. In addition, with the increasing capacity of modern ship power system, the cable layout has become a prominent problem. Therefore, the existing power distribution system has been gradually unable to adapt to the needs of development, and regional distribution technology can achieve the above goal of reducing the construction cost of the power system and improving the ship vitality through the division of the whole ship area.

Regional distribution is to divide the power system of the whole ship into several regions according to the nature and size of the load. Connecting lines or busbars are used to form a hierarchical network between regions. Each power station can guarantee the power supply of the load in one or several regions. When a fault occurs in an area, the fault area should be isolated in a minimum range to ensure the normal operation of other equipment as far as possible. In addition, regional distribution technology can reduce the construction cost of power system and improve the vitality of ships by dividing the whole ship into different regions.

2.2 Regional distribution network scheme

After the division of the area, due to the different number of components and equipment used and the connection mode, the regional distribution system may have a variety of structural forms [24], the following are several typical forms.

1. Scheme one

As shown in figure 5, is the operation mode of single bus (in the figure, IL represents the important load, CL represents the common load, the same below). The regional switchboard is only connected to one side of the ring power supply network through the circuit breaker. The important load is directly connected to the regional switchboard, while the ordinary load is connected to the regional switchboard through the distribution box, circuit breaker or isolation switch. The equipment is simple, the structure is clear, and the short-circuit current calculation is convenient.

Obviously, in this area, the distribution mode is a typical dry feed type, which mainly USES the reliability of the ring power supply to ensure the continuous power supply to the important load. When the ring bus is disconnected somewhere, the power supply can still be obtained in this area. In this scheme, a variety of electrical equipment is the least used, and the cables are the shortest, but the reliability is low. If the circuit breaker or the line between the bus and the regional switchboard fails, the entire region will suffer from power failure. At the same time, if the connected bus segment is removed due to failure, the region will also suffer from power failure. The scheme does not give full play to the advantages of ring power supply and the reliability of important load power supply is not very high.

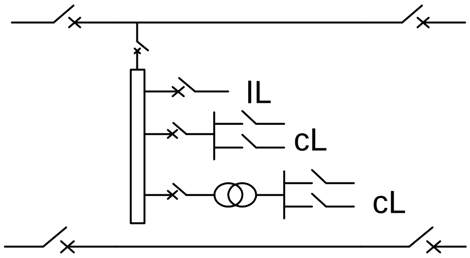


Fig.5 Scheme 1

2. Scheme two

As shown in figure 6, the scheme is an improvement of scheme 1, in which each regional switchboard receives power from the bus on the left and right sides through the circuit breaker. When damage occurs at one end of the bus, the power supply of the area switchboard can be automatically/manually transferred to the other side of the bus. Even if a circuit breaker or line between the bus and the area switchboard fails, the power supply of the area switchboard can still be obtained from the other side, so as to ensure the strong vitality of the area distribution.

The monitoring computer manages the load through the area distribution board and realizes the distribution of the load. This mode in the region is essentially a dry - fed hybrid distribution, equivalent to double - power supply. The important loads are directly connected to the area distribution board, while the minor and ordinary loads are supplied by the distribution box. This connection mode is simple and clear, the analysis and calculation is slightly complex, the cable length is short, and at the same time to ensure the important load supply reliability, cost-effective.

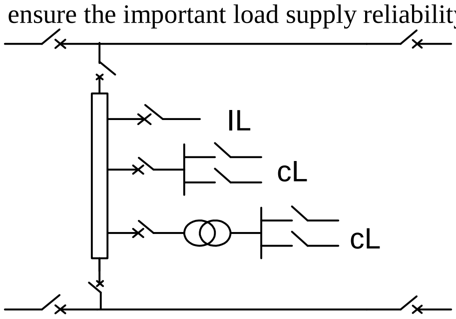


Fig.6 Scheme 2

3. Scheme three

As shown in Figure 7, it is evident that the scheme is the evolution of scheme 2, where two regional distribution boards are connected in parallel in one area, and each regional distribution board leads to buses in two directions through circuit breakers. For important loads, power supply can be obtained from two regional distribution boards, thus reducing the possibility of power outage to important loads caused by damage to distribution components and further improving it. Power supply reliability of important loads. Ordinary loads are supplied by secondary or tertiary distribution boxes. At the same time, due to the existence of two regional distribution boards, the load capacity of each regional distribution board can be reduced correspondingly, and the load capacity of the whole region can also be increased. According to the following data calculation, this method has the highest reliability and the strongest vitality of the important load. But obviously, the equipment is too redundant, wasteful and low cost. If the reliability of various distribution equipment is high enough, it is not suitable to adopt this method.

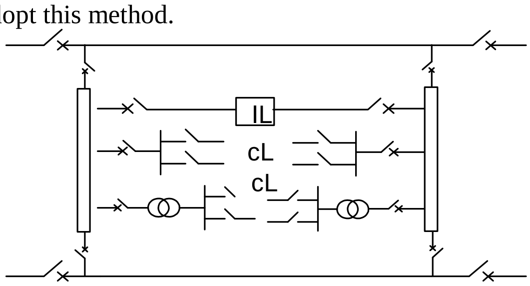


Fig.7 Scheme 3

4. Scheme four

As shown in Figure 8, the distribution mode uses a dual-area distribution board to form a ring, which can relatively accommodate more loads and improve load capacity. The power supply is still introduced through circuit breakers on both sides of the ring power supply network. Important loads are supplied by two regional distribution boards, while ordinary loads are connected to the nearest regional distribution board. The analysis shows that the scheme is similar to the 30 points of the scheme. Since both bus lines are connected to each area distribution board through circuit breakers at the same time, any fault at one end can ensure the continuity of power supply in the whole area. At the same time, because of the formation of ring power supply in the region, the reliability of power supply of any load is relatively high, and the vitality of important load is relatively strong. In theory, if the regional distribution board does not fail, and the load capacity is enough, one distribution board is enough to maintain the reliability of the power supply of the entire regional system, it is not necessary to use two regional distribution boards, which results in waste of equipment, and the cost performance is poor as the third scheme.

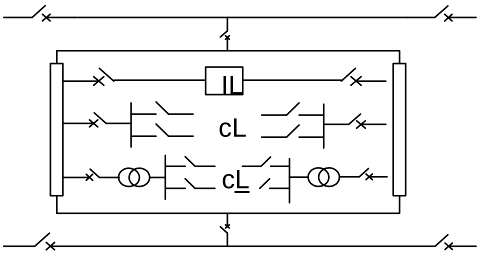


Fig.8 Scheme 4

3. Research on Reliability of Ship Power Grid

3.1 Reliability Analysis Method of Distribution System

Using the reliability analysis method of land power system for reference, the following indicators can be adopted:

(1) Load point failure rate (sub/a)

Failure rate (secondary/annual): refers to the number of blackouts caused by component failures or overhauls of distribution systems at load points per unit time (usually one year).

(2) Average outage time R (h/times) per fault at load point

Average outage time (hour/time) refers to the average duration of each outage caused by component failure or overhaul of the distribution system at the load point.

(3) Average annual outage time at load point U (h/a)

Annual blackout time (hour/year): refers to the number of blackouts caused by component failures or overhauls of distribution systems at load points per unit time (usually one year). The above three indicators have the following relationship:

$$U_i = \lambda_i \times r_i \quad (1)$$

It can be concluded that each reliability index:

$$SAIFI = \frac{\sum \lambda_i N_i}{M} \quad (2)$$

$$SAIDI = \frac{\sum U_i N_i}{M} \quad 3)$$

$$CAIFI = \frac{\sum \lambda_i N_i}{Z} \quad (4)$$

$$CAIDI = \frac{\sum U_i N_i}{Z} \quad (5)$$

$$ASAI = \frac{M \times 8760 - \sum U_i N_i}{M \times 8760} \quad (6)$$

Where, λ_i is annual power failure rate at the load point;

U_i is annual blackout time of load point;

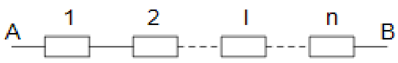
N_i is the number of load points affected each time;

M is total load points supplied by the system;

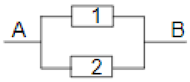
Z is total number of load points affected.

(1) Reliability model of series system

A series system is a system consisting of two or more components. Failure of any of the components constitutes a system failure. In a series system, all components must be intact at the same time for the system to work properly. FIG. 9 (a) is the reliability network model of the series system composed of N elements. According to markov process theory, formulas applicable to engineering calculation can be derived to obtain the equivalent parameters of the series system:



(a)Reliability model of series system



(b) Reliability model of parallel system

Fig.9 Serial and parallel model

$$\lambda = \sum \lambda_i \quad (7)$$

$$r = \frac{\sum \lambda_i r_i}{\sum \lambda_i} \quad (8)$$

$$U = \sum \lambda_i r_i \quad (9)$$

Where, λ_i and r_i respectively represent the failure rate (time/a) and average repair time (h/time) of components in the series system; λ、r and U respectively represent the failure rate (time/a), average failure repair time (h/time) and annual average power failure time (h/a) after the series system is equivalent.(2) reliability model of parallel system A system consisting of two or more repairable components in parallel must fail at the same time in order for the system to fail, or as long as one of the components is intact, the system is intact. As shown in FIG. 9(b), the reliability network model of the parallel system composed of two independent components can also be used to obtain the reliability calculation formula and equivalent parameters of the parallel system through markov process theory

$$\lambda = \lambda_1 \cdot \lambda_2 (r_1 + r_2) \quad (2.15)$$

$$r = \frac{r_1 \cdot r_2}{r_1 + r_2} \quad (2.16)$$

$$U = \lambda r = \lambda_1 \lambda_2 r_1 r_2 \quad (2.17)$$

Where, λ_i and r_i respectively represent the failure rate (time/a) and average repair time (h/time) of components in the series system; λ、r and U respectively represent the failure rate (time/a), average failure repair time (h/time) and annual average power failure time (h/a) after the series system is equivalent. Similarly, the reliability calculation formula and equivalent parameters of multi element parallel system can be obtained

3.2 reliability parameter calculation

First, reliability parameters of related components are selected according to generally accepted standards, as shown in table 1.

According to the structure of different regional distribution network, the network simplification idea is used to decompose it into the simplest series or parallel model, and then the above reliability calculation formula is used to calculate the reliability index of the above regional distribution network structure and single busbar dry-feed structure. It is assumed that the load of each structure is the same, that is, two important loads and two common loads, and the power supply is reliable, only the reliability index of the distribution network part is calculated. Taking the reliability calculation of single busbar structure for important loads as an example, it is illustrated as follows.

Table1 Reliable parameters of components

	power distribution busbar	circuit breaker	load switch	line	Automatic switch
Failure rate (time/year)	0.002	0.007	0.005	0.001	0.001
Repair time (hours)	30	10	8	20	5

Firstly, all the power supply paths to the load are determined, and the failure mode and consequence analysis table are established according to all the components and lines in series or in parallel on the paths. As shown in figure 8, there is only one power supply path for important loads, starting from the bus end and passing through the circuit breaker and regional switchboard, which are all in series. During calculation, the distribution bus and branch wires must be connected in series to find out the reliability parameters of each component. Then the reliability of the system is calculated according to the reliability calculation rules.

The calculation results are shown in table 2 and table 3, which are the reliability index of the system and the power supply reliability parameter of the load, respectively.

According to the data comparison, scheme one, that is, the most commonly used single bus distribution system, has the lowest reliability and the highest failure rate of important loads. The second scheme makes good use of the advantages of ring power supply. The reliability of the system and the important load is very high, and the equipment is not very complex. The third scheme is similar to the second scheme, which ensures the higher reliability of the system and the important load by means of a large amount of redundancy of the equipment. Comparisons show that scheme 3 has the highest reliability, but the equipment redundancy is also the largest. Scheme 4 can be used as a compromise between scheme 2 and scheme 4, and its reliability is also between them. Obviously, the equipment redundancy is still very high. From the structure, it can be seen that as long as the regional distribution board is connected to the bus part with high reliability, a regional distribution board can ensure the power supply of the whole regional system to continue, so the second scheme is a feasible one.

Table 2 Reliable index of systems

	ACI	*CID*	*SAIFI*	*SAIDI*	*CAIDI*	*ASAI(%)*
Scheme 1	0.086	1.28	0.0215	0.32	14.88	99.9958
Scheme 2	0.06	0.62	0.0151	0.154	10.19	99.998
Scheme 3	0.042	0.384	0.011	0.096	9.14	99.9987
Scheme 4	0.0474	0.453	0.0118	0.113	9.56	99.998

Table3 Parameters of important loads

	λ (times/year)	*r* (Hours / times)	*U* (honr/year)	*ASAI* (%)
Scheme 1	0.019	15.79	0.30	99.9966
Scheme 2	0.01262	10.626	0.1341	99.9985
Scheme 3	0.0034	5.313	0.018	99.9998
Scheme 4	0.00606	8.614	0.0522	99.9994

4. Scheme improvement

On the basis of scheme 2, further improvements can be made. That is to say, the most important load in each area is connected to two area distribution boards through automatic or manual switching switches. These two area distribution boards can be in adjacent areas or in non-adjacent areas. Cables introduced by another area distribution board can be placed in parallel with buses in order not to cross the watertight silo, as shown in Figure 11. In this way, when the power supply system in one area fails, the most important load can still be maintained to be supplied by the distribution board in another area, so that the reliability of the most important load can be better guaranteed and the vitality of the ship can be improved. Through the above analysis and the following reliability calculation results (see Table 4), it can be seen that the improved scheme is more practical and can be used as the first choice of the scheme.

Table4 Reliable results of the vital loads

parameter	λtimes/year)	*r* (Hours/times)	*U* (honr/year)	*ASAI* (%)
Most Important Load	0.0044	5.23	0.023	99.9997

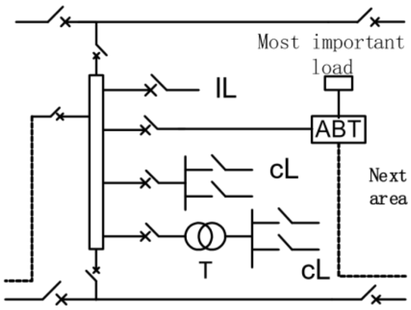


Fig.11 Improved zonal scheme

5. Conclusion

From the above comparative analysis, it can be seen that the ship annular regional distribution network has higher reliability than the radial distribution network, is more flexible in the construction process, and can ensure the vitality of the ship, so it is the future direction of development. However, there are also many shortcomings in the ring-shaped regional distribution system, which need to be solved a series of problems, such as the difficulty of short-circuit current calculation and the complexity of management and dispatch. In addition, from the perspective of power system relay protection, relay protection will be more complex because the ring-shaped network can form multiple paths from generator to load, but with the progress of science and technology, the management level will be improved. The problem will be solved step by step. Ring power grid and even grid power grid will be popularized on ships.

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