CSCanada
Management Science and Engineering
Vol. 8, No. 2, 2014, pp. 93-97
DOI: 10.3968/5023

ISSN 1913-0341 [Print]
ISSN 1913-035X [Online]
www.cscanada.net
www.cscanada.org

Reliability Research of Power Distribution System For Important Units at the Airfield

XUE Zhengyu[a],*; ZHANG Tao[a]; CHENG Yanrong[a]

[a]Depatment of Airfield Engineering Air Force logistics Institute, Xuzhou, China.
*Corresponding author.

Received 12 Jnauary 2014; accepted 11 May 2014
Published online 16 June 2014

Abstract

Important power units at the airport are the direct units of aviation security, the reliability of power supply and distribution system directly affect the safety of it for aviation security. This paper analyzes the important units of electricity power supply system into the units of reliability. The basic reliability model and the mission reliability model are constructed respectively and the corresponding reliabilities are calculated. Then the paper studies on the relationship between two kinds of reliability as well as the influence on the reliability of power supply and distribution system, providing theoretical basis of planning, equipment selection, engineering design, reliable operation and maintenance management for important units of power supply system.

Key words: Important power unit; Power supply and distribution system; The basic reliability; The task reliability

Xue, Z. Y., Zhang, T., & Cheng, Y. R. (2014). Reliability Research of Power Distribution System For Important Units at the Airfield. *Management Science and Engineering*, *8*(2), 93-97. Available from: URL: http://www.cscanada.net/index.php/mse/article/view/5023
DOI: http://dx.doi.org/10.3968/5023

INTRODUCTION

The important power units at the airport are the basic units of electricity to guarantee the function of airport. According to the "Airport the Power Supply Engineering Standard (try out)", the important power units include: the airport flight control room, meteorological station, tower, visual navigation lights substation, communication station, navigation station, main water pump room and terminal platform (Department of infrastructure, 2004). The important units of electricity supply and distribution system generally adopt the double 10 kV or 35 kV City Mains into line, also belonging to the city electricity network terminal. In order to ensure the power supply reliability of the important units, airports all have self-built spare power station or uninterruptible power supply system (UPS) to compose the grid power supply system with the city mains. So the structure of power supply system of important units is complex and requires high reliability, the research of the power supply reliability must carry out.

1. POWER SUPPLY AND DISTRIBUTION SYSTEM OF IMPORTANT POWER UNITS

Power supply and distribution system of the important power units at the airport are at the Figure 1.

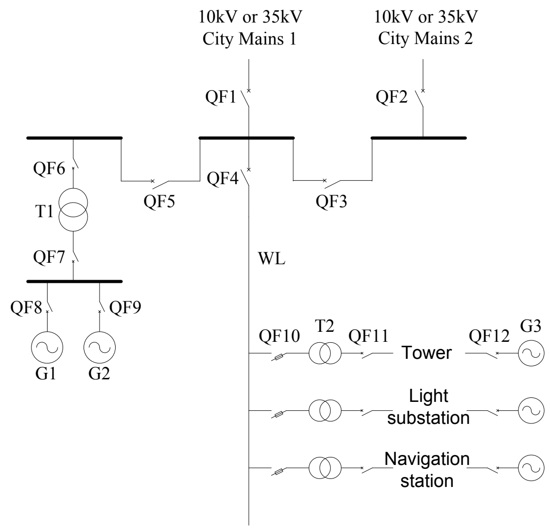

Figure 1
Power Supply and Distribution System of the Important Power Units at the Airport

Figure 1 lists only tower, light substation and navigation station three important power units, the rest of the important units are the same connection as three units of picture 1, all are connected in parallel to the line WL. Because the important power units are parallel each other, so this article illustrates the form of power supply and distribution system of important power units in the example of the control tower.

(1) City Mains. Power supply and distribution system generally use two 10 kV or 35 kV mains supply, one of them is used and the other is prepared. On the normal, the power of city mains (common power supply) supplies power, namely the 10 kV or 35 kV City Mains 1 in Picture 1, the other mains are prepared, namely the 10 kV or 35 kV City Mains 2 in Picture 1.When the common power supply malfunctioned, QF1 disconnected, contact switch QF3 is closed, and standby power switched on, continuing to supply power.

(2) Spare Power. Once both city mains supply is interrupted, the two generators G1 and G2 of airport standby power plant start and operate in parallel. Then the city mains power switch QF1, QF2 and QF3 are opened, contact switch QF5 closed, the low-voltage electricity generated by G1 and G2 is boosted by transformer T1 to 10kV or 35kV and continues into important units of the airport.

(3) Through the cable WL of the important units. Close the high voltage switch QF4, 10 kV or 35 kV high voltage powers supplied by cable WL and transformer T2 to reduce into 380V / 220V, then through the low voltage switch QF11 and connects with the command equipment of the control tower. In addition to further guarantee the power supply reliability, each important power units of airport also have dedicated generating set, namely the G3 in Picture 1, it provides low voltage power supply to control tower through the low voltage switch QF12 directly.

2. THE RELIABILITY MODEL OF POWER SUPPLY AND DISTRIBUTION SYSTEM OF IMPORTANT POWER UNITS

2.1 Division of Model Units

Reliability model can be divided into basic reliability model and the mission reliability model. Basic reliability relates to the duration of the trouble-free or probability of the product on prescribed conditions. It reflects the demand for maintenance of human product. It uses the average time between failures (MTBF) as a general reliability parameter. Basic reliability model is used to estimate the maintenance and security requirements of the product and its component units, and is a series model. Mission reliability is the ability to make regulation function of the product within the specified mission profile, reflecting the requirement of mission success, usually uses mission reliability (*MR*) as a general reliability parameter (Yang, Ruan, Yu & Tu, 2004). Mission reliability model is used to estimate the probability to complete the required function of product in the process of performing tasks, describes the due role in the process of each unit to complete the task, and is used to measure the effectiveness of task. Therefore, mission reliability model is established by the reliability block diagram and mathematics models according to the function and the logical relationship between them. It shows the relationship between various devices to complete the task required by the system reliability, through a variety of series, parallel, beside and hybrid combinations of typical model.

The reliability model of the distribution system of essential power units includes reliability block diagram and its mathematical model. Reliability block diagram refers to the logic diagram of system failure of each component or their combination under the function of power supply for power supply and distribution system. Considering important units of power supply system diagram, the units of the block diagram will be divided into the following:

Table 1
Units Classification

Unit	Name	Reliability $R(t)$	Failure rate (1/h)
1	10 kV or 35 kV city mains 1	R_1	λ_1
2	10 kV or 35 kV city mains 2	R_2	λ_2
3	Into the line switch QF1	R_3	λ_3
4	Into the line switch QF2	R_4	λ_4
5	Contact switch QF3	R_5	λ_5
6	High voltage switch QF4	R_6	λ_6
7	Switch QF5	R_7	λ_7
8	High voltage switch QF6	R_8	λ_8
9	Step-up transformer T1	R_9	λ_9
10	Low voltage switch QF7	R_{10}	λ_{10}
11	Low voltage switch QF8	R_{11}	λ_{11}
12	Low voltage switch QF9	R_{12}	λ_{12}
13	Generator G1	R_{13}	λ_{13}
14	Generating set G2	R_{14}	λ_{14}
15	Field line WL	R_{15}	Λ_{15}
16	High voltage switch QF10	R_{16}	λ_{16}
17	Step-down transformer T2	R_{17}	λ_{17}
18	Low voltage switch QF11	R_{18}	λ_{18}
19	Generator G3	R_{19}	λ_{19}
20	Low voltage switch QF12	R_{20}	λ_{20}

The reliability of each unit is the basis of the overall system reliability. The reliability and the failure rate of Unit 1 and 2 in Table 1 can be obtained from the relevant data of city mains supply department. The rest of the units are electrical equipment, their life generally obeys exponential distribution, and their reliability and the failure rate can be obtained from specifications of related equipment.

2.2 The Basic Reliability Model

Basic reliability model is for the requirement of maintenance and security estimation of the unit failures, so all component unit of the reliability block diagram is in series (Chen & Chen, 2007) [3]. Any unit failure in the whole power supply system will result in the basic reliability of the whole system. 20 units are in series to form reliability block diagram, as Figure 2:

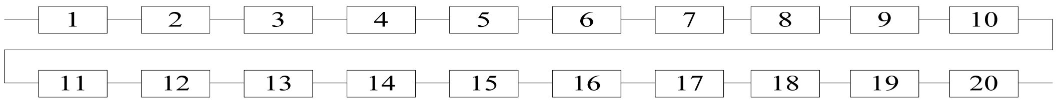

Figure 2
The Basic Reliability Block Diagram

From the basic reliability block diagram:

$$R_{sj}(t) = \prod_{i=1}^{20} R_i(t) \quad (1)$$

$$\lambda_{sj} = \sum_{i=1}^{20} \lambda_i \quad (2)$$

$$MTBF_{sj} = 1/\lambda_{sj} \quad (3)$$

Then basic reliability $R_{sj}(t)$ and mean time between failures $MTBF_{sj}$ are resulted, and the basic reliability parameters of units of electricity power supply system are resulted.

2.3 Mission Reliability Model

Mission reliability of power supply and distribution system is the ability of completing regulated function within the prescribed task profile. The mission profile of the power supply system of important units at the airport is connected with the line between power mains and power units. The regulated function is to ensure the normal operation of power supply equipment without failure.

The basic reliability model is a serial model, to establish it is simple. The task reliability model is different, should be carried out according to the following procedure (Li & Wang, 2006).

2.3.1 Determine the Task Profile

The basic reliability model of a complex system is the only, but to establish mission reliability model needs to firstly clear task profile. The mission profile of electricity power supply system of important units at the airport is to ensure that the line connected, thus power supplied. From airport power supply system of important power units, namely the Picture 1, City mains 1 and 2 are in hot standby, so they can be considered as parallel to each other, and in normal times they are the main power of the whole system. Then they connected to QF1, QF4, WL, QF10, T2, QF11 in the series, to be power supply line of the tower.

2.3.2 To Determine Whether There Is A Substitute Working Mode

When the system can complete a specific function in a variety of methods, it has substitute working mode. So they should be painted as a substitute model in the mission reliability block diagram. From picture 1: each important power unit has their own dedicated airport standby generator set to the main road, between it and the main way, “detect and transform device①” is to implement, and reliability of “detect and transform device①” is set to 1. The self-built total spare power station of Airport is the spare circuit of mains supply, between them is “detect and transform device②”, the reliability of “detect and transform device②” is also set to 1.

2.3.3 Determine the Failure Criterion

The failure criterion of mission reliability refers to the failure affects product task to complete. It should identify parameters and boundary values when the task is not successful and the conditions when the task is in failure. Failure criterion should be specified for to each unit to find, namely finding the kinds of failure and the failure rate of each unit by the statistic.

2.3.4 Determine the Task Time Model

The using time of equipment or system is the parameter of reliability function, so it must be modified in the establishment of mathematical model (Zong, 2002). The whole system time is set to *t*.

2.3.5 Determine the Environmental Conditions

A system or product often can be used in different circumstances, or a particular task may work for several stages, each stage has its corresponding specific environmental conditions. Mission reliability model should be to fix when environmental factors considered.

The using environment of the power supply system of important units at the airport is the daily power supply environment of the airport.

Therefore, to establish the reliability block diagram of power distribution system of important power units at airport, as in Figure 3:

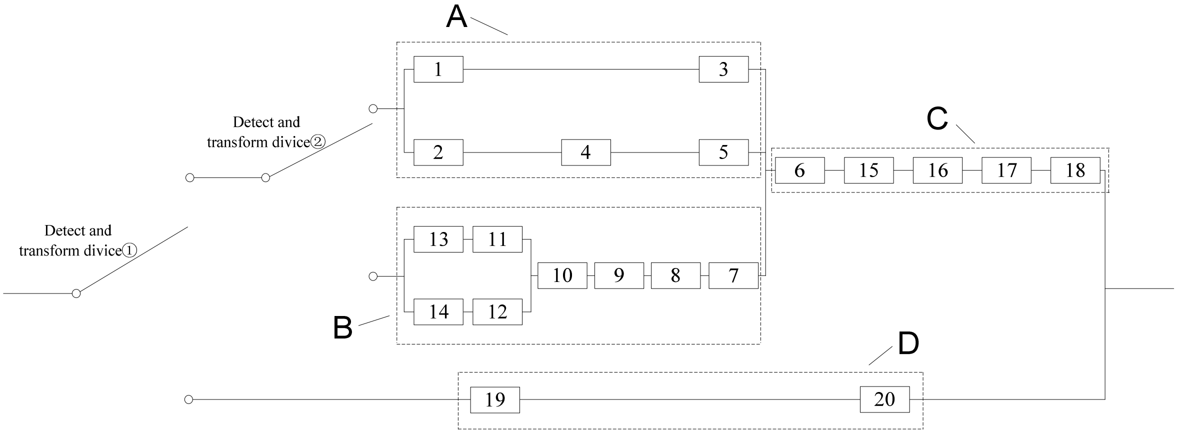

Figure 3
Mission Reliability Block Diagram
Note. Part A is two parallel mains supply; Part B is self-built standby power station of the airport; Part C is able WL to tower load; Part D is own special generating set of tower.

By mission reliability block diagram, to calculate the mission reliability.

Part A of the diagram is power supply reliability of the two city mains:

$$R_A(t)=(1-R_1R_3)(1-R_2R_4R_5) \quad (4)$$

Part *B* is the power supply reliability of airport self-built standby power station:

$$R_B(t)=[1-(1-R_{13}R_{11})(1-R_{14}R_{12})]R_{10}R_9R_8R_7 \quad (5)$$

Assume that the failure rate of each unit of power supply and distribution system is in the plateau, namely not changing over time. So consider the failure rate of a system of all the units in part A and part B is constant, so $R(t)=e^{-2\lambda t}$, so part A:$\lambda_A=-\ln R_A(t)/t$ and part B: $\lambda_B=-\ln R_B(t)/t$.

For redundant system composed of two different units compose of part A and part B, the failure rates are respectively the constants of $\lambda_A$and λ_B:

$$R_s(t)=\frac{\lambda_B}{\lambda_B-\lambda_A}e^{-\lambda_A t}+\frac{\lambda_A}{\lambda_A-\lambda_B}e^{-\lambda_B t} \quad (6)$$

Then the reliability of main power supply of the road after connected by Part C is as:

$$R_{main}(t)=R_s(t)R_6R_{15}R_{16}R_{17}R_{18} \quad (7)$$

The power supply reliability of part D, namely own special generator of power unit at airport is as:

$$R_{sub}(t)=R_{19}R_{20} \quad (8)$$

Also consider the failure rate of the system of all the units in the main road and dedicated generating set are constant, so $R(t)=e^{-\lambda t}$, so the main road: $R_{main}=-\ln R_{main}(t)/t$, the alternate route: $R_{sub}=-\ln R_{sub}(t)/t$.

For redundant system composed of two different units, the failure rate constants are $\lambda_{main}$and λ_{sub}respectively, and the reliability of overall system is as:

$$R_{overall}(t)=\frac{\lambda_{sub}}{\lambda_{sub}-\lambda_{main}}e^{-\lambda_{sub}t}+\frac{\lambda_{main}}{\lambda_{main}-\lambda_{sub}}e^{-\lambda_{sub}t} \quad (9)$$

So the parameter of mission reliability (*MR*) of the power supply system is resulted, namely $R_{overall}(t)$.

3. THE RELATIONSHIP BETWEEN THE TWO KINDS OF RELIABILITY AND THE IMPACT ON THE RELIABILITY OF POWER SUPPLY AND DISTRIBUTION SYSTEM

From the statistical data of 8,800 h in Chifeng Airport and Yixian Airport as an example to calculate two reliable, such as Table 2.

According to reliable model, reliability parameters of the basic reliability and mission reliability for the distribution system can be calculated. Basic reliability parameter is the mean time between failures and reliability $MTBF_{sj}$. Mission reliability parameters are $R_{overall}(t)$, namely the mission reliability. Through the determination of these two parameters, it can effectively evaluate the whole reliability of power supply and distribution system:

If basic reliability is too low, the reliability of basic units of power supply and distribution system is low, and the device may have quality problems. As Chifeng Airport in Table 2, Rsj(t)=0.882, the basic reliability is low, then analyze the unit reliability of Chifeng Airport in Table 2, the reliability of switching QF8 is low, so there may be quality problems and need to repair.

Table 2
The Reliability of Chifeng Airport and Yixian Airport

Unit	Name	Chifeng airport (t=8,800 h)		Yixian airport (t=8,800 h)	
		Reliability $R(t)$	Failure rate (1/h)	Reliability $R(t)$	Failure rate (1/h)
1	10 kV city mains 1	0.998	2×10^{-7}	0.999	1×10^{-7}
2	10 kV city mains 2	0.998	2×10^{-7}	0.999	1×10^{-7}
3	Switch QF1	0.996	5×10^{-7}	0.996	5×10^{-7}
4	Switch QF2	0.996	5×10^{-7}	0.996	5×10^{-7}
5	Switch QF3	0.995	6×10^{-7}	0.995	6×10^{-7}
6	Switch QF4	0.995	6×10^{-7}	0.995	6×10^{-7}
7	Switch QF5	0.999	1×10^{-7}	0.996	7×10^{-7}
8	Switch QF6	0.998	2×10^{-7}	0.999	1×10^{-7}
9	Transformer T1	0.997	3×10^{-7}	0.997	3×10^{-7}
10	Switch QF7	0.998	2×10^{-7}	0.999	1×10^{-7}
11	Switch QF8	0.974	3×10^{-6}	0.998	2×10^{-7}
12	Switch QF9	0.991	1×10^{-6}	0.998	2×10^{-7}
13	Generator G1	0.982	2×10^{-6}	0.996	7×10^{-7}
14	Generating set G2	0.982	2×10^{-6}	0.996	7×10^{-7}
15	Field line WL	0.996	5×10^{-7}	0.997	3×10^{-7}
16	Switch QF10	0.998	2×10^{-7}	0.998	2×10^{-7}
17	Transformer T2	0.997	3×10^{-7}	0.997	3×10^{-7}
18	Switch QF11	0.996	5×10^{-7}	0.995	6×10^{-7}
19	Generator G3	0.993	8×10^{-7}	0.996	7×10^{-7}
20	Switch QF12	0.996	5×10^{-7}	0.997	3×10^{-7}
	$MTBF_{sj}$	70,422 h		1,280,000 h	
	$R_{sj}(t)$	0.882		0.941	
	$R_{overall}(t)$	0.937		0.977	

If the difference between with basic reliability and mission reliability is too big, it is generally believed that more than 30% of the difference (Liu & Cao, 2007), the planning structure of power supply and distribution system is unreasonable, system redundancy is too big. The difference of basic reliability between mission reliability of two airports in Table 2 is not exceeded 30%, so the planning structure of the distribution system is reasonable, and system redundancy is appropriate.

CONCLUSION

Through the establishment of reliability model of important units at airport of electricity power supply system, it provides the reliability analysis and calculation methods of operation mode of the power supply and distribution system, in which the division of model elements is good for failure rate statistics and reliability calculation of each unit, ultimately determine the parameters of the system reliability. Finally it provides a theoretical basis for planning, equipment selection, engineering design, and reliable operation and maintenance management of the power supply system of important units at the airport.

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