Analyzing a Capability of Specifying a Failure Area in a Space Solar Power Satellite

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Abstract

A space solar power satellite (SSPS) has some difficult problems which other type of satellite does not have. One of problems is difficulty of fault diagnosis. SSPS is a huge satellite; therefore it is hard to specify a failure area when failure occurres. To address this issue, we proposed three methods[1] (i.e. self-module decision method, adjoining module decision method, and center module decision method) to specify a failure area for SSPS. Special feature of these methods is autonomous distribution system, which is a good solution to improve the performance of fault tolerant system. To estimate the performance of methods comprehensively, we make simulations and investigate results of simulation. As the result, we arrive at the conclusion that the function "disconnect" is the very important function to specify a failure area. From those reason and results, the adjoining module decision method whit the function "disconnect" is suitable from the viewpoint of reliability.

1. Introduction

Failure diagnosis is a very critical issue to maintain the function of the satellite. In addition to these problems, it should be noticed that we should start by specifying a failure area at the first step of failure diagnosis. This can be easily understood by considering a very big satellite like a solar power satellites (SSPS)[2]. This is because SSPS has very large scale structure and may be damaged frequently by debris or high level radiation. To address this issue, some methods were proposed [3][4][5][6]. One of those methods called highly structured system [6]. It is a failure diagnosis system for distributed network system including intermittent faults. The intermittent fault is a type of fault at the context of distributed system. If an object has intermittent fault, it will perform normal operation and abnormal operation periodically. The intermittent fault is an origin to make the failure diagnosis difficulty. The effectiveness of highly structured system is proved mathematically, but the highly structured system cannot diagnose a failure if concentration of intermittent fault objects over the limit of this system [6]. To overcome upon limit, our previous research [1] proposed three methods (1) self-module decision, (2) adjoining module decision and (3) center-module decision method to specify a failure area for SSPS. These methods are based on autonomous and distributed processing of each module which constitutes a satellite. However, their usefulness is only analyzed at the limited situation through the simulation, and therefore this research aims at conducting several simulations in a realistic situation to investigate a capability of our methods.

This paper is organized as follows. Sections 2 explain the SSPS. Section 3 describes the difficulty of failure diagnosis including intermittent faults. Section 4 explains the three methods of specifying a failure area, and Section 5 gives simulations. We discuss results in Section 6. Finally, the discussion and conclusion is given in Section 7 and Section 8.

2. Space Solar Power Satellite

The SSPS[2] has a power generates system that mounts many solar cells. Since the SSPS generates electric power by sunlight, the amount of energies is almost infinite. In addition to this advantage, the SSPS neither depends on weather nor pollutes a space when generating an electric power.

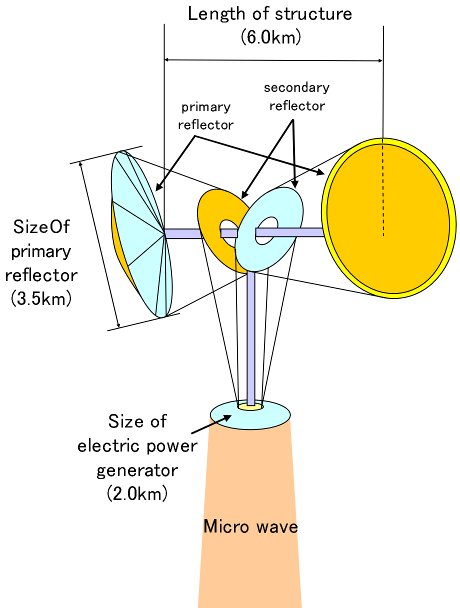


Figure 1: Space solar power satellite

However, in order to generate the electric power that can take a profit economically, the SSPS should be built as a very big satellite. As shown in Figure 1, the scale of the SSPS that JAXA plans now is a very big system. Concretely, the large two circles located at the outside indicate the primary reflectors, while the small two circles located at the inside indicate the secondary reflectors. The bottom of the circle finally indicates the electric power generator. The sizes of the primary reflector and the electric power generator are about 3.5Km and 2.0Km, respectively. The length of the structure that connects the primary reflectors is about 6.0Km. In Figure 1, the bottom direction is the direction to the earth. To generate the electric power, the primary reflectors reflect the sunlight, and the reflected sunlight goes toward to the secondary reflectors. Then, the secondary reflectors reflect the sunlight to the electric power generator. The electric power generator gathers the sunlight and generates an electric power. Finally, a generated electric power is changed to microwave to send to the earth.

Figure 2 shows a part of the electric power generator seen from the upper side angle of Figure 1. Each power generation module shown as hexagon constitutes a power generation part, and each module connects with the adjoining modules by the electric communication line and information line indicated by the dash line. In this research, we focus on the failure in this part and address where the power generation modules break down.

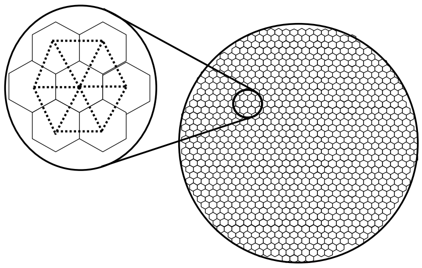


Figure 2: Electric power generator of SSPS

2.1 Structure of generator module

Figure 3 shows the structure of generator module we consider. The module consists of four parts: generator panel, voltage sensor, CPU, and line disconnector. The generator panel makes electronic power from sunlight. Electronic power flows to the power line via the voltage sensor. The voltage sensor measures voltage value and it to CPU. The CPU receives measured voltage and sends its value and the command depending on the methods. Each module connects to the around six modules by the power line and communication line. The line disconnector disconnects the power line and communication line by the command by its own module or other modules depending on the methods. The power line transfers electric power from the generator panel. The communication line exchanges each module data and command. We use only communication line for fault diagnosis.

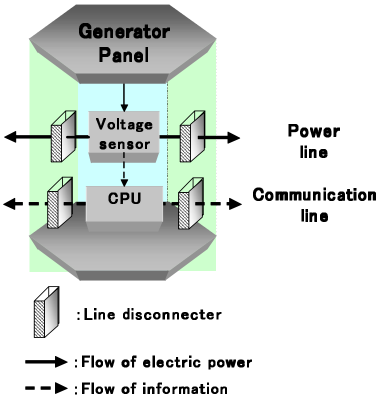


Figure 3: Structure of generator module

3. Difficulty in fault diagnosis including intermittent faults

Generally, an existence of intermittent fault makes failure diagnosis difficult. This is because intermittent faults act normal and abnormal. From this reason, a value measured from intermittent faults may change whenever measuring the value. Therefore, we cannot find intermittent fault modules quickly. As the result, the intermittent fault modules may decide other modules state incorrectly which causes bad influence on other parts. This problem makes fault diagnosis more difficult.

4. Three methods for specifying a failure area

In this section, we explain our proposal methods, i.e., the self-module decision method, the adjoining module decision method, and the center module decision method.

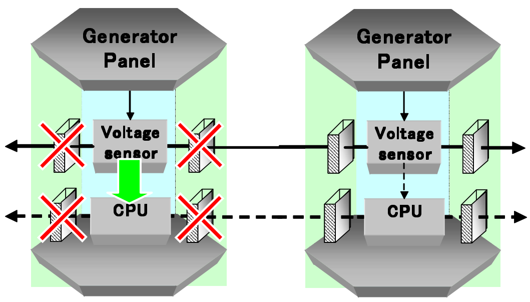


Figure 4: Self-module decision method

The self-module decision method checks its own states itself. The flow of decision is shown as follows:

(1) The voltage sensor sends the measured voltage to own CPU.
(2) The CPU receives the measured voltage.
(3) If the measured voltage is the same as the correct value, the CPU decides own state normal; otherwise decides abnormal.
(4) If the state is abnormal, the CPU sends the disconnect command to own line disconnector.
(5) If the line disconnector receives the disconnect command from own CPU, it disconnects all own power line and communication line from connected modules.

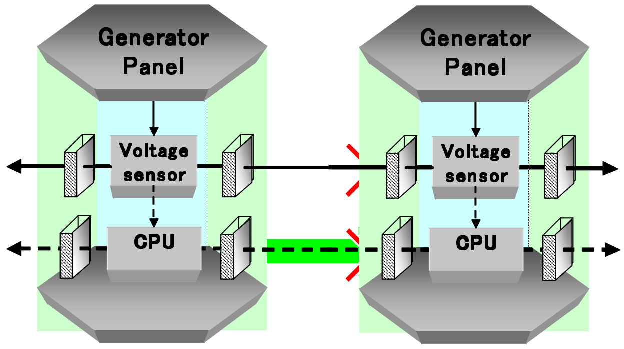


Figure 5: Adjoining module decision method

The adjoining module decision method checks connected module states. The flow of decision is shown as follows:

(1) The voltage sensor sends the measured voltage to own CPU.
(2) The CPU receives the measured voltage.
(3) The CPU sends the measured voltage to connected modules.
(4) Connected modules receive the measured voltage.
(5) If the received measured voltage is the same as the correct value, The CPU decides the connected module state normal; otherwise decides abnormal.
(6) If the connected module state is abnormal, the connected module is broken. The CPU sends the disconnect command to own line disconnector.
(7) If the line disconnector receives the disconnect command from own CPU, it disconnects power line and communication line from broken module.

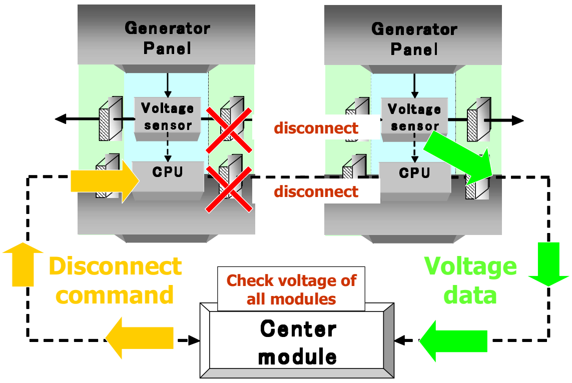


Figure 6: Center module decision method

The center module decision method checks all modules states. The flow of decision is shown as follows:

(1) The voltage sensor of each module sends the measured voltage to own CPU.
(2) The CPU receives the measured voltage.
(3) The CPU sends the measured voltage to the center module.
(4) If the received measured voltage is the same as the correct value, the center module CPU decides state of module which sends the data normal. Otherwise decides abnormal.
(5) If the state is abnormal, the modules which sends the data is broken, the center module CPU sends the disconnect command to line disconnector of modules connected to the broken module.
(6) If the line disconnector receives the disconnect command from center module CPU, it disconnects the power line and communication line from broken modules.

5. Simulation setup and evaluation

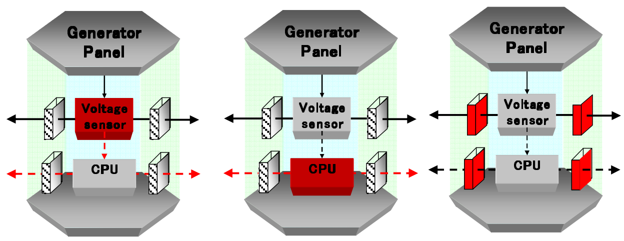
The simulation parameters are set as follows:

(1) Number of modules：2500
(2) Number of debris:1
(3) Size of debris:2size(small debris, large debris(i.e., small debris*4))
(4) Probability of the error work in broken modules:5%,10%,30%, and 50%
(5) State of disconnector: normal or broken

We employ the step for evaluate. Step means a time period from the first line disconnect to the last line disconnect

Type of failure

We address three types of failures, voltage sensor failure, CPU failure, and line disconnector failure. If voltage sensor breaks down, it may send abnormal value (0v) depending on the probability of the error work. If CPU breaks down, it may decide incorrectly depending on the probability of the error work. For example, when CPU breaks down with the probability 0.5%, CPU decides the state "abnormal" in 0.5% and "normal" in 95%. If the state of disconnector is "abnormal", the disconnector cannot disconnect according to the CPU command "disconnect".



Voltage sensor failure CPU failure Line disconnector failures

Figure 7: Type of failure

Combination of failures

We use six combinations of failures for three methods as shown in table 1. We use three types of failures (i.e., sensor failure, CPU failure and, disconnector failure) as a simple failure and 4 types of failure combination as a multiple failure. The Sensor failure + CPU failure indicate that both sensor and CPU break down. The Sensor failure + disconnector failure indicate that both sensor and disconnector break down. The CPU failure + disconnector failure indicate that both CPU and disconnector break down. The CPU failure + sensor failure + disconnector failure indicate break down all.

Table 1 Combination of failure

Simple failure	Multiple failure
Sensor failure	Sensor failure + CPU failure
CPU failure	Sensor failure + disconnector failure
Disconnector failure	CPU failure + disconnector failure
	CPU failure + sensor failure + disconnector failure

6. Result

We show relation of methods and combinations of failures shown from Figure 8 to 19. In all figures, z axis indicates the step to from the first disconnect to last disconnect. 8, 9, 11, 14, 15, 17 x axis indicates the rate of sensor broken rate, and y axis indicate the method type. In figure 10, 12, 13, 16, x axis indicate the rate of sensor broken rate, and y axis indicates the rate of CPU broken rate. From figures, we find that step become shorter depending on the rate of rate of sensor broken rate. Debris size and step has a relation. Debris size becomes larger, step become longer.

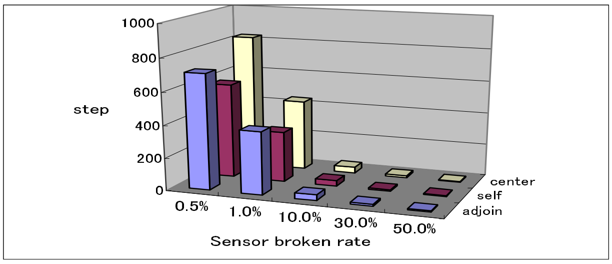


Figure 8: Step, sensor broken rate and methods (small debris)

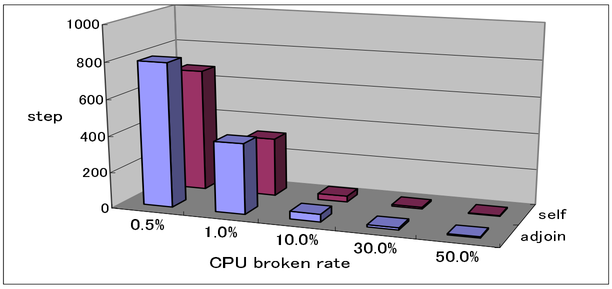


Figure 9: Step, CPU broken rate and methods (small debris)

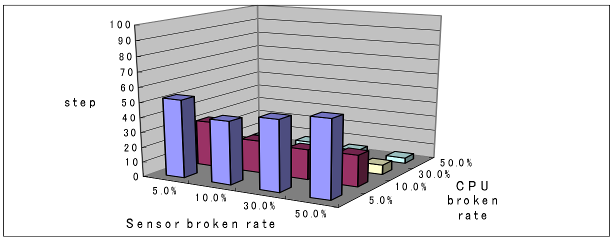


Figure 10: Step, CPU broken rate and sensor broken rate in adjoin module decision method (small debris)

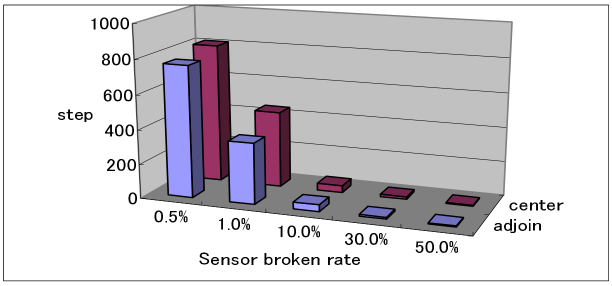


Figure 11: Step, sensor broken rate, disconnector broken and methods (small debris)

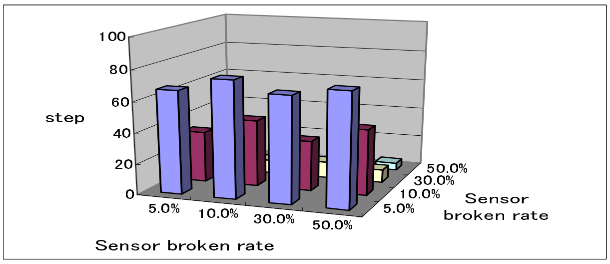


Figure 12: Step, CPU broken rate, sensor broken rate in adjoin module decision method (disconnector broken) (small debris)

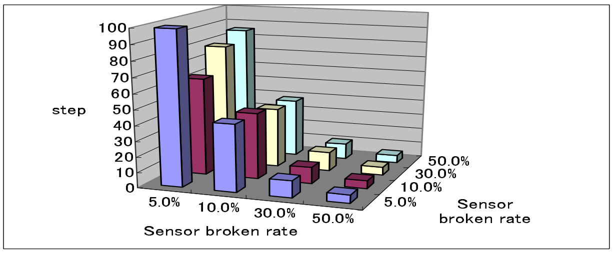


Figure 13: Step, CPU broken rate, sensor broken rate in self-module decision method (small debris)

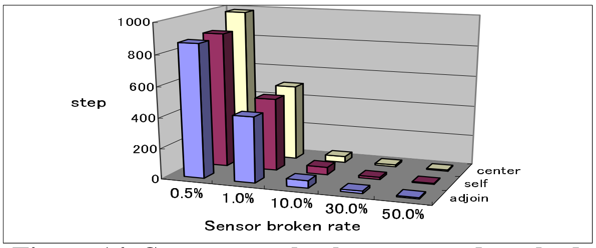


Figure 14: Step, sensor broken rate and methods (large debris)

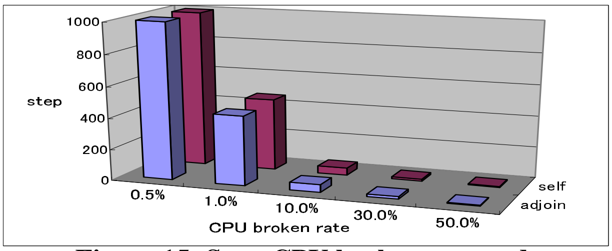


Figure 15: Step, CPU broken rate and methods(large debris)

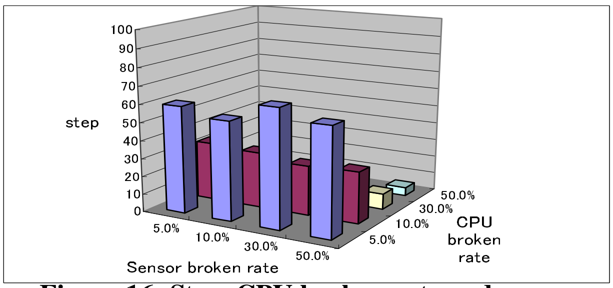


Figure 16: Step, CPU broken rate and sensor broken rate in adjoin module decision method(large debris)

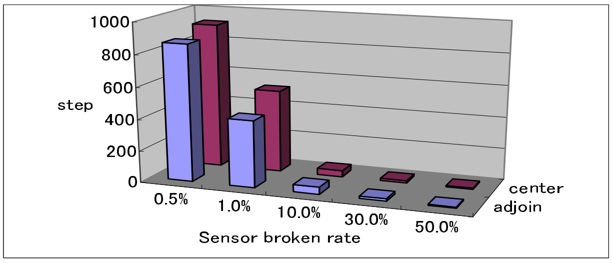


Figure 17: Step, sensor broken rate, disconnector broken and methods (large debris)

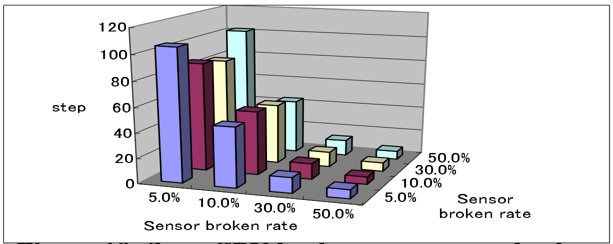


Figure 18: Step, CPU broken rate, sensor broken rate in adjoin module decision method (disconnector broken)(large debris)

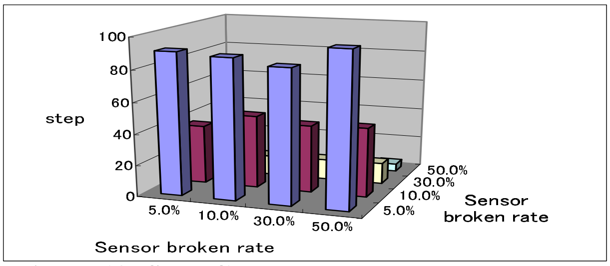


Figure 19: Step, CPU broken rate, sensor broken rate in self-module decision method (large debris)

7. Discussion

Table 2 shows summary of result. ○ indicate that meshed can specify a failure area, while × indicate meshed cannot. From this table, we can find that the self-module decision method has a weakness of disconnector fault, while the center module decision method has a weakness of CPU fault. In comparison with those methods, adjoining module decision method has no weakness. From the result of simulation and summary, the adjoining module decision method is a superior method because of robustness to several combinations of faults.

8. Conclusion

In this research, we analyzed the capabilities of following the methods that specify a failure area in the SSPS: (1) the self-module decision method, (2) the adjoining module decision method; and (3) the center module decision method. To estimate the performance of methods comprehensively, we make simulations in many cases to change the parameter and situation. From the investigation of results, we find that adjoin module decision method has robustness to several combination of faults

Table 2: Summary of result

failure \ method	Self decision	Adjoin decision	Center decision
Sensor	○	○	○
CPU	○	○	×
Disconnector	×	○	○
Sensor + disconnector	×	○	○
CPU + disconnector	×	○	×
Sensor + CPU	○	○	×
Sensor +CPU + disconnector	×	○	×

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