Research On Prevention And Improvement Of AC Overcurrent In Static Inverter

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Abstract—**The Static Inverter (SIV) failed occurs on the mainline of the EMU. It must be repaired and reset by the main work shop after the passenger evacuation, which will result in great loss in operation. The main purpose of this study is to find the root cause which influences the SIV abnormal performance. Through fault tree analysis (FTA) method and laboratory test, we found that sensor feedback is the main factor, not the SIV device self. The improvement is to add the limiter device at the position after the ramp starting in the current controller output. The voltage command will not rise rapidly when the static inverter (SIV) starts, then it will be verified by following the validation steps in the laboratory. These results can be used for reference in other railway systems. Whether it is a Static Inverter (SIV) in the form of GTO or IGBT, Inverter AC Over-Current (IAOC) issues can be solved.**

Keywords—**Railway Vehicle, Propulsion System, Auxiliary Power Supply System, Static Inverter(SIV), Inverter AC Over Current(IAOC)**

I. Introduction

High-volume and medium-volume electric interlinked vehicles are rail cars that run on 750 V DC power. Vehicle power is divided into two types: the propulsion system and the auxiliary power supply system. The auxiliary power system uses static commutation. The device (SIV) is the upstream of the device, like the gasoline of a car and the blood of the human body, and plays an important role in the power system [1].

The static inverter (SIV) converts the input DC power of 750 V into three-phase AC power (AC380 V). The circuit provides high-frequency independent PWM (pulse width modulation) control, three-phase independent control, and transient voltage waveform control. [2] After the power is distributed, it will be delivered to air-conditioning, air compressors, cooling fans, lighting, clean electricity, on-board 4G mobile Wi-Fi, train control, communication signals, luggage systems and all miscellaneous equipment, DC supply, etc.al.

If the power supply is often cut off due to overcurrent for unknown reasons, it will cause operational troubles and losses. This study is based on the fact that since the first detection of the AC overcurrent (IAOC) of the static converter (SIV) on October 12, 2016, the AC overcurrent (IAOC) has occurred 20 times so far. All AC overcurrent (IAOC) after the static converter (SIV) has started operation (after the converter gate is activated) were detected. Based on the protection device design, the software finds that the static converter (SIV) has continuously detected four alternating overcurrent (IAOC). The IGBT gate and IVK (Inverter Contactor) of the static converter (SIV) will stop functioning as been locked off.

The current solution can only transfer the train back to the maintenance airport. According to the reset method and steps, at first, turn off the control power, then, open the static converter (SIV) equipment box, and finally, press the "inverter field reset" button in the SIV box[3] and temporarily solve the problem of AC overcurrent (IAOC).

Although each train will have two sets of equipment to supply electricity for the entire car, according to the current collection standards, as long as a group of static converters (SIVs) fail, operations must be stopped. This is not only a problem for passengers, but also causes operations Difficulties in dispatching available cars, peak cars, and spare cars are required, so suppliers Mitsubishi Electric are requested to assist in research on how to prevent and improve them.

II. Methods

When the static converter (SIV) fails, you can download detailed waveforms and find the cause of the failure through a computer program. In addition, in the absence of high-voltage power, the timing test can be used for self-diagnosis. According to the start/stop time chart, start conditions, start timing, etc. al. [4], applying a 600 ms ramp start when the static converter (SIV) starts to operate can reduce the inrush current, as shown in Figure 1.
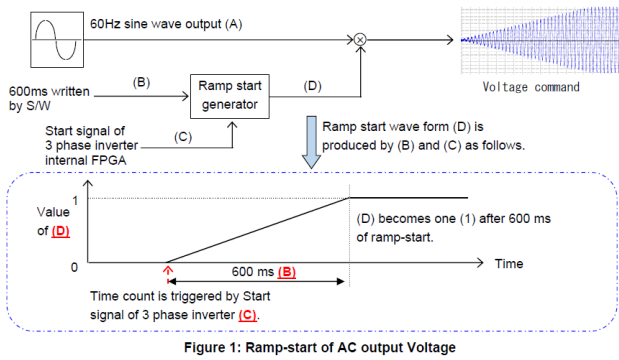
Figure 1: Ramp-start of AC output Voltage

We found that when the AC overcurrent (IAOC) is detected, it is the AC output voltage generated when the static converter (SIV) is started without a ramp. Download the fault tracing data from the computer, as shown in Figure 2.
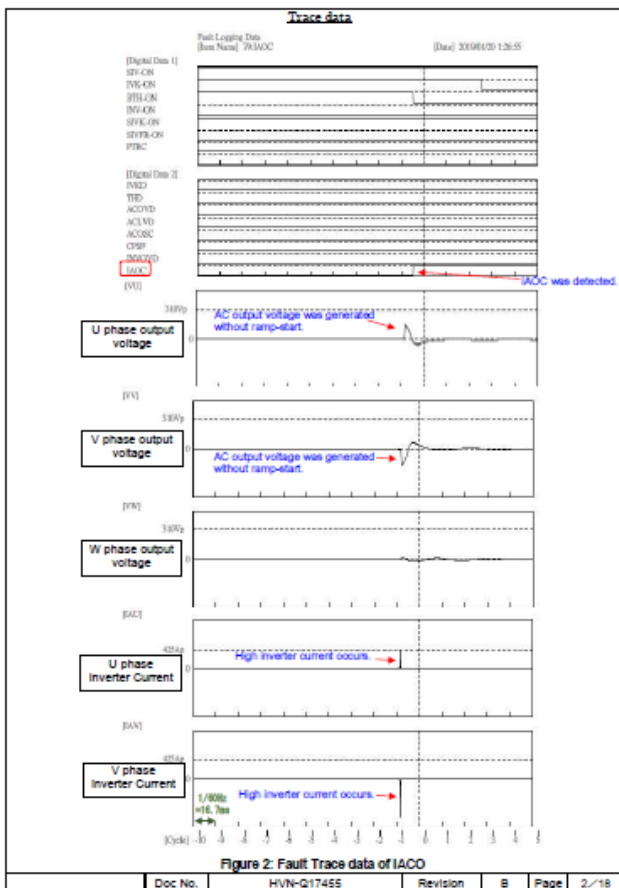

Figure 2: Fault Tracking Data for AC Over Current (IAOC)

Based on the fault conditions, this study draws a fault tree analysis (FTA) [5] for AC overcurrent (IAOC) detection, and analyses and studies corresponding to the fault tree analysis (FTA) [5] program is shown in Figure 3.
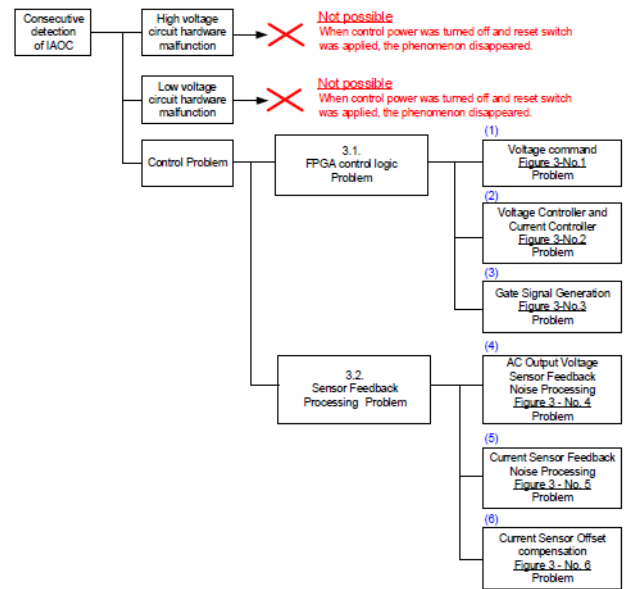

Figure 3: Fault Tree Analysis (FTA) of IAOC detection

According to fault tree analysis (FTA) [5], hardware faults of high-voltage and low-voltage circuits can be eliminated, because when the control power is turned off and the reset switch is used, the fault phenomenon has disappeared (if the hardware fault is caused by the appearance of the cause of the problem, the phenomenon will not disappear even if the control power is turned off), so we excluded the hardware failure from the study.

We found that the "control problem" was the cause of the failure. We conducted the following six studies on the "control problem":

1. FPGA control logic vs. voltage instruction: (1) in Figure 3

2. FPGA control logic vs. voltage controller and current controller: (2) in Figure 3

3. FPGA control logic vs. Generate gate control signal: (3) in Figure 3

4. Sensor feedback signal processing vs. voltage sensor noise processing: (4) in Figure 3

5. Sensor feedback signal processing vs. current sensor noise processing: (5) in Figure 3

6. Sensor feedback signal processing vs. current sensor offset compensation: (6) in Figure 3

In addition, the control block diagram of the static converter (SIV) is shown in Figure 4 [6], so that we can further understand the correlation of fault tree analysis (FTA) [5].
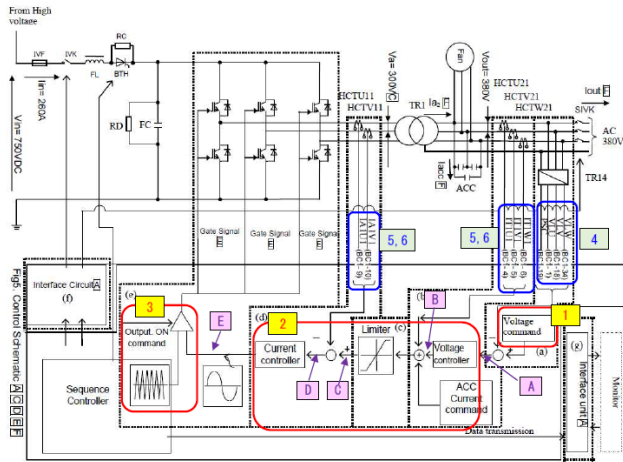
Figure 4: Control block diagram of SIV

In short, Field Programmable Gate Array (abbreviated as FPGA) is a product developed on the basis of programmable logic devices such as PAL, GAL, CPLD, etc. It is for the special application integrated circuit field, a kind of semi-customized circuit appears, which not only solves the shortcomings of the fully customized circuit, but also overcomes the shortcoming of the limited number of gate circuits of the original programmable logic device. [7]

Because the circuit details are in the professional scope of Mitsubishi Electric, Mitsubishi Electric was commissioned to conduct the following verification in a Japanese laboratory. First, study the "FPGA control logic problem" shown in (1), (2), and (3) of Figure 3:

1. Carry out 7100 control power off / on tests to simulate the use of the control unit, and the result shows no problem.

2. Compare with the original design requirements and check the FPGA logic. The result shows no problem.

3. Check the tracking data of "Voltage Command", the result shows no problem.

Based on the results of the lab study above, the reasons not form FPGA control logic.

After knowing the results, the problem of sensor feedback signal processing shown in Figure 3 is the crux of the problem. The difference between laboratory tests (control unit only) and train conditions (high voltage conditions) was considered in this study. And under high voltage conditions, voltage/current sensor feedback may be anomalous data. Therefore, in the laboratory, the following tests are performed on the "sensor feedback signal processing problem" shown in (3), (4), (5), and (6) in Figure 4:

1. Normal condition of voltage/current sensor feedback:

In the laboratory test, first check the normal start-up condition, and the voltage/current sensor feedback does not have any abnormality. The test results show that when the

static inverter (SIV) starts to operate (the gate is activated), the output of "voltage command", "voltage controller" and "current controller" gradually increases, as shown in Figure 5.
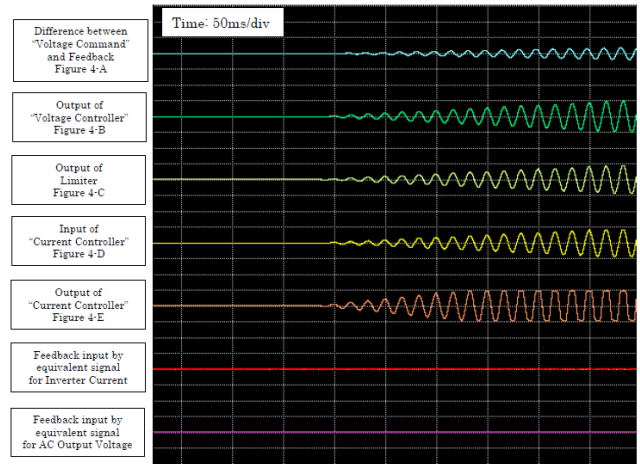

Figure 5: Normal start test without any abnormal on sensor feedbacks

2. AC output voltage sensor feedback processing (Figure 3 (4)):

In laboratory tests, noise is applied to the AC output voltage sensor feedback. The test results show that after the static converter (SIV) starts to operate (the gate is activated), the output of the "current controller" (the final output of the gate control signal) increases rapidly, as shown in Figure 6.
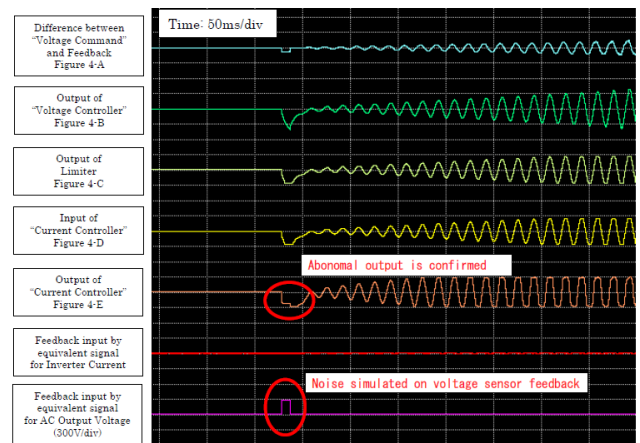

Figure 6: When noise is applied on AC output voltage sensor feedback

Normally, when the static converter (SIV) starts to operate, the output of the "current controller" should gradually increase as the ramp starts. However, when we are applying noise, the output of the "current controller" increases rapidly, which causes the AC output voltage to increase rapidly.

However, the voltage causes the surge current (overcurrent) generated by the converter to the AC filter capacitor (ACC) as described above, which is one of the causes of the alternating current overcurrent (IAOC).

3. Current sensor feedback processing (Figure 3 (5)):

In laboratory tests, we apply noise to the AC output current sensor feedback or the converter current sensor feedback. The test results show that after the static converter (SIV) starts to operate (the gate is activated), the output of the "current controller" (the final output of the gate control signal) increases rapidly, as shown in Figures 7 and 8.
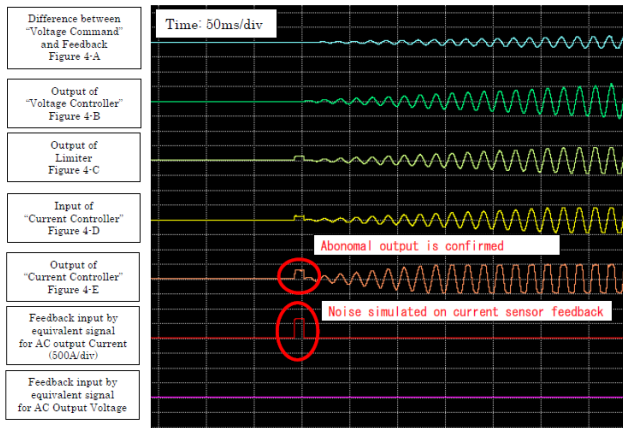

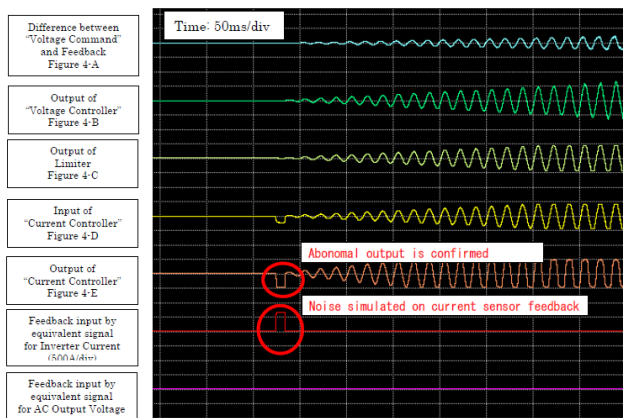Figure 7: When noise is applied on AC output current sensor feedback

Figure 8: When noise is applied on Inverter current sensor feedback

When the static converter (SIV) starts to operate, the output of the "current controller" should gradually increase as the ramp starts. However, when noise is applied, the output of the "current controller" increases rapidly, which causes the AC output voltage to abnormally increase rapidly. After that, the voltage causes an inrush current (overcurrent) from the inverter to the AC filter capacitor (ACC), which is one of the causes of the AC overcurrent (IAOC).

4. Current sensor offset compensation (Figure 3 (6)):

If the AC output current sensor or inverter current sensor is shifted, the output value of the "current controller" cannot be zero even if the actual current is zero. In laboratory tests, an offset is applied to the AC output current sensor or converter current sensor. According to the test results, confirm that the "current controller" has no abnormal output, as shown in Figure 9 and Figure 10. The current sensor offset does not cause the output of the "current controller" to increase rapidly, so the current sensor offset does not cause ac overcurrent (IAOC).
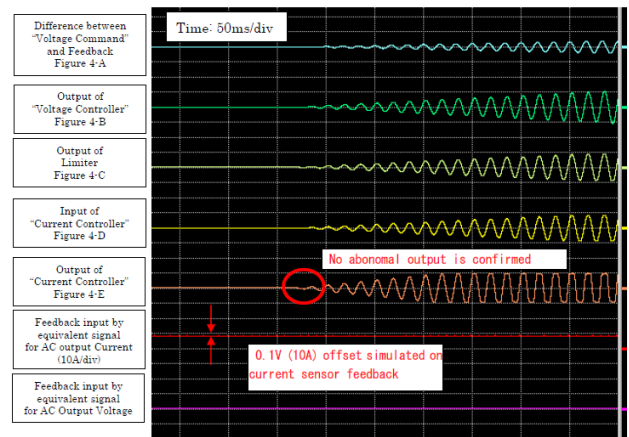

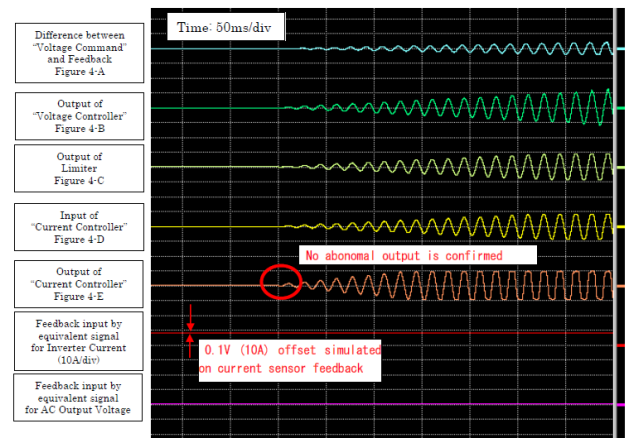Figure 9: When there is offset on AC output current sensor

Figure 10: When there is offset on Inverter current sensor

III. Results

According to the results, the causes and solutions of the AC overcurrent (IAOC) are shown in Table 1.

Table 1: Matrix Cause and Countermeasure of IAOC

No.	Cause	Problem	Countermeasures	
			Necessity	Method *(Note 1)*
(1)	Processing of noise on AC output voltage sensor feedback	Voltage controller generates value when it shall be zero (0).	Necessary	Add limiter in output of "Current Controller"
(2)	Processing of noise on the current sensor feedback	Current controller generates value when it shall be zero (0).	Necessary	
(3)	Processing of offset on current sensors	This is not cause of IAOC. No problem.	Not necessary	-

According to the research results, it is confirmed that even if noise is applied to the voltage/current sensor feedback, the output of the "current controller" does not increase rapidly. Therefore, it is confirmed that the improvement plan will solve the problem of AC overcurrent (IAOC), and the test results are summarized in Table 2.

Table 2: Summary of test result after applying the counter measure

No.	Test Condition	Result	Evaluation	Chart
1	Normal start (Same as Section 3.2 (1))	The output of "Current Controller" did not increased rapidly	OK	Figure 12
2	Noise was added on the voltage sensor feedback (Same as Section 3.2 (2))	The output of "Current Controller" did not increased rapidly	OK	Figure 13
3	Noise was added on the current sensor feedback (Same as Section 3.2 (3))	The output of "Current Controller" did not increased rapidly	OK	Figure 14 Figure 15

IV. **Conclusions & Contributions**

Based on empirical results, the following important conclusions are obtained:

1. Static converter (SIV) is not caused by ac overcurrent (IAOC) caused by FPGA.

2. Think about the crux of the problem with fault tree analysis (FTA).

3. IAOC caused by sensor feedback processing signals.

4. Increasing the limiter after the ramp is activated can effectively improve the noise.

References

[1] Chen Guangli, February 91. MRT Technology Semi-annual Issue, Issue 26, Introduction to Heavy-duty Electric Vehicle Propulsion and Auxiliary Power System, 173 ~ 200

[2] KHI, 2010. Auxiliary Equipment/Static Inverter Detail Design for rolling stock, CKS-ME01-DDD-ERS-0008 Rev.0, 11

[3] KHI, 2010. Auxiliary Equipment/Static Inverter Detail Design for rolling stock, CKS-ME01-DDD-ERS-0008 Rev.0, 40~44

[4] KHI, 2010. Auxiliary Equipment/Static Inverter Detail Design for rolling stock, CKS-ME01-DDD-ERS-0008 Rev.0, 34~39

[5] Shi Bojie, 2008. Using Fault Tree and Event Tree Analysis to Discuss the Risk of Level Crossing Accidents, Master's Thesis, Department of Transportation Management, National Cheng Kung University

[6] KHI, 2010. Auxiliary Equipment/Static Inverter Detail Design for rolling stock, CKS-ME01-DDD-ERS-0008 Rev.0, 33

[7] Qiu Yongzhang, 2001. Design of IGBT Power Component Tester Based on FPGA, Master's Thesis of Institute of Electrical Engineering, Chang Gung University

[8] Luo Heyuan, Huang Senrong, He Xianglin, August 1987. Civil Water Conservancy, Volume 25, Phase 2, Discussion on the Traction Power Configuration of Taipei MRT System, 83 ~ 93

[9] He Zongxuan, Tian Rongsheng, Huang Zhiqiang, and Cai Yulin, August 1995. MRT Technology Semi-annual Issue, Issue 35, Electric Vehicle Electric Equipment, 25 ~ 129

[10] Hongyu Huang, 2016. Development and Application of IGBT Switch Circuit with Current Limit Protection, Master's Thesis, Department of Electrical Engineering, National Cheng Kung University

[11] Concise politics, 2013. Development of IGBT Static Converter Modules for Electric Vehicles